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The Application of Satellite and Radar data in Thunderstorm Research

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled The Application of Satellite and Radar data in Thunderstorm Research submitted by James Grant Wieler in partial fulfilment of the requirements for the degree of Master of Science in Meteorology.

Dedication

To Shelley,

and my parents,

neither time nor distance,

could diminish their

loving support.

Abstract

A technique is presented for determining cloud-top temperatures, cloud cover, and cloud type, from the combination of infrared and visible TIROS-N Automatic Picture Transmission (APT) data. These data are implemented in the study of convective storms over Alberta in July 1979 and 1980.

Infrared cloud-top temperatures, and associated heights derived from concurrent radiosonde ascents are compared to values derived by conventional methods such as the parcel method, and range-height indicators from radar data. Consideration of the possible errors involved in each method, imply that satellite derived cloud-top temperature and height measurements are the most accurate, economical, and representative estimates available.

Convective rain areas as determined from low-level PPI's are compared to the results of an algorithm combining visible and infrared data. The results, although encouraging, are dependent on both the season, and the thunderstorms stage of development.

The methods presented can provide a variety of products with detail sufficient for use in meso-scale analysis of cloud patterns.

Acknowledgements

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1. The Observation of Thunderstorms from Satellites

1.1 Introduction

Thunderstorms have roused the imagination of man since time immemorial. The Greek God Zeus, the most powerful of the gods, was reputed to control lightning and thunder. Today thousands of man-hours and millions of dollars are spent each year so that we may someday understand and possibly control that phenomenon the ancients attributed to their gods.

With the launching of TIROS-1 on April 1, 1960, man entered into a new era of meteorological understanding. During the past twenty years, the data produced by meteorological satellites have steadily become more refined.

The first earth-orbiting satellites were able to produce imagery in the visible part of the spectrum only. As a result, early work with satellite data (Anderson and Veltishchev, 1973) consisted primarily of observing pictures to identify cloud and circulation patterns. Today meteorological satellite sensors transmit detailed visible, infrared, and microwave information covering the globe. From these data it is possible to determine cloud type (Harris and Barrett, 1978), estimate precipitation (Martin and Scherer, 1973), forecast precipitation (Bellon et al., 1980), and derive vertical temperature soundings (Phillips, 1979; Smith et al., 1979).

Most of the recent research in the area of satellite meteorology has concentrated on data from geosynchronous operational environmental satellites (GOES). The fine temporal resolution of GOES data is particularly useful in the study of cloud pattern movements. Fortunately, the work done with GOES data can be related to polar orbiting satellite data, provided the fine temporal resolution of the former is not considered.

The observation of convective storms over central Alberta by TIROS-N satellite data recorded at the University of Alberta, and S-band (10 cm) radar data collected in Penhold, Alberta by Alberta Research Council have provided a data base for this study. The derivation of a cloud -top temperature model using satellite data, its implications, and comparison between satellite products and radar data will be discussed in this thesis.

1.2 The Structure of Thunderstorms

Several categories of thunderstorms such as squall lines, multicell, supercell, and severely–sheared thunderstorms have been identified (Marwitz, 1972a,b,c). Of these, the squall line, which is composed of multi cell storms, is the most frequently observed over central Alberta. The severely–sheared storm is a subset of the supercell category; therefore, the majority of all thunderstorms fall into either the multicell or supercell category.

All thunderstorms consist of at least one updraft –downdraft pair, referred to as a convective cell. According to Byers and Braham (1949) these cells go through several stages of development as summarized in Table 1.1.

A multicell storm is simply a conglomerate of individual cells moving in an organized pattern. New cells develop periodically on the right–hand flank facing the direction of motion of the storm, growing to maturity as they move into, and become part of, the storm complex. Multicell storms appear to move to the right of the environmental wind due to this flanking development. Individual cells in a multicell storm tend to retain their identity and can be tracked by radar for up to thirty minutes.

In contrast to the highly time–dependent multicell storm, supercell storms retain their characteristics over a longer period of time, typically 30 to 60 minutes and, on occasion, as long as several hours. These supercell storms are most often characterized by a single persistent cell which generally travels to the right of the mid–tropospheric (700–300 mb) winds. The physical makeup of these storms permits the updraft and precipitation fallout (downdraft) to exist separately. Thus, the resulting storm is what may be termed a "continuous flow" phenomenon (Chisholm and Renick, 1972), changing its air several times during its existence. During the mature stage of a supercell storm the storm top, as determined by radar, shows slight vertical variations, typically not more than one kilometer from the mean height.

Table 1.1 Thunderstorm stages of development.

Stage	Characteristics	Duration
Cumulus	updraft throughout cloud, cloud tops 25–30,000 feet	10–15 minutes between first radar echo and initiation of rain at ground.
Mature	strong updraft and downdraft, cloud tops 40–60,000 feet	15–30 minutes
Dissipating	updraft cut off at low levels by downdraft, falling cloud tops	approx. 30 minutes, after which vertical velocities are insignficant.

1.3 The Utility of Satellite Data in Thunderstorm Studies

Satellite data have the advantage over other meteorological observation systems in that they provide continuous spatial coverage over a very large area. These data can, moreover, provide information over areas where no conventional meteorological data are available.

Analyzed Automatic Picture Transmission (APT) data from TIROS–N can be a very useful tool in the study of convective storms. The derivation of cloud climatologies, cloud cover and type, cloud–top temperature and height, can be of great value in the study of interactions between the meso and synoptic scales. The combination of visible and infrared data to yield precipitation areas is useful in studying storm energetics, since precipitation is a fundamental indicator of the amount of latent heat released within a storm. The ability to monitor the coverage of rain over land is important because of its direct impact on crop production. Moreover, the destructive effects of heavy rainfall and hail could be reduced by more accurate forecasts based on satellite data.

The orbital period of TIROS–N is approximately 102 minutes, a period far greater than the lifetime of most multicell storms (30 to 60 minutes). Although the temporal resolution of the TIROS–N data is inadequate for studying cloud motions, its spatial resolution (4 km) at 51° north is far superior to that of the infrared GOES data (16 km) at 51° north.

2. Satellite Instrumentation

2.1 Introduction

The satellite information used in this study was obtained from TIROS-N, a third generation polar orbiting environmental satellite. Since a comprehensive discussion of the TIROS-N satellite system can be found in Schwalb (1978), only a general description of the TIROS-N Automatic Picture Transmission (APT) system will be given here.

The TIROS-N satellite series has been designed to operate in a sun-synchronous orbit at a height of 865 km. The satellite has a period of approximately 102 minutes , a westward nodal regression of 25.59^0, and is inclined 98.8^0 from the equator. The satellite precesses eastward at a rate of one degree per day, so that the satellite maintains a nearly constant orientation over the course of the year.

2.2 Satellite Scanning

The satellite carries on board an Advanced Very High Resolution Radiometer (AVHRR); this is a four-channel scanning radiometer sensitive in the visible (0.5–0.9 μm), near infrared (0.725–1.10 μm), (3.55–3.93 μm) and far infrared (10.5–11.5 μm) window regions. The APT signal consists of the visible and far infrared channels from the AVHRR. These channels are time-division multiplexed into an output stream that is processed by the onboard computer to achieve both bandwidth reduction and geometric correction. The bandwidth reduction algorithm involves sending one of every three scan lines produced by the AVHRR to the APT transmitter. Each scan line consists of 700 individual pixels representing the radiometer's output while scanning from horizon to horizon. The geometric correction is performed to maintain constant resolution along the scan; this is accomplished by using a separate resolution reduction in each of five regions on either side of the satellite sub-point. The algorithm is summarized below and the results shown in Figure 2.1.

Region 1	(±16.9° from nadir): average four contiguous samples
Region 2	(16.9° to 34.8° either side of nadir): average two samples skip one and repeat
Region 3	(34.8° to 43.8° either side of nadir): average two samples
Region 4	(43.8° to 48.8° either side of nadir): average one and one half samples
Region 5	(48.8° to 55.4° either side of nadir): retain original resolution

All of this processing is accomplished in the digital domain before being converted into an analog signal for output on the APT transmitter.

The AVHRR contains a mirror which rotates at 360 revolutions per minute. However because of the bandwidth reduction the effective rotation for the APT signal is 120 scans per minute, or 2 scans per second. This rotation, perpendicular to the satellite's path, combined with the motion of the satellite gives complete coverage of the area in the field of of view of the radiometer. The field of view of the scanning radiometer is restricted to be within 55.4° of the satellite sub–point in order to minimize the effect of atmospheric attenuation and limb darkening. These "artificial" horizons restrict the satellite scans to 27° of longitude at the equator (2997 km). Since the satellite regresses 25° per orbit, there is a 2° overlap between consecutive orbits at the equator. This overlap increases with the latitude such that the area over central Alberta is in the radiometer's view during four orbits each day.

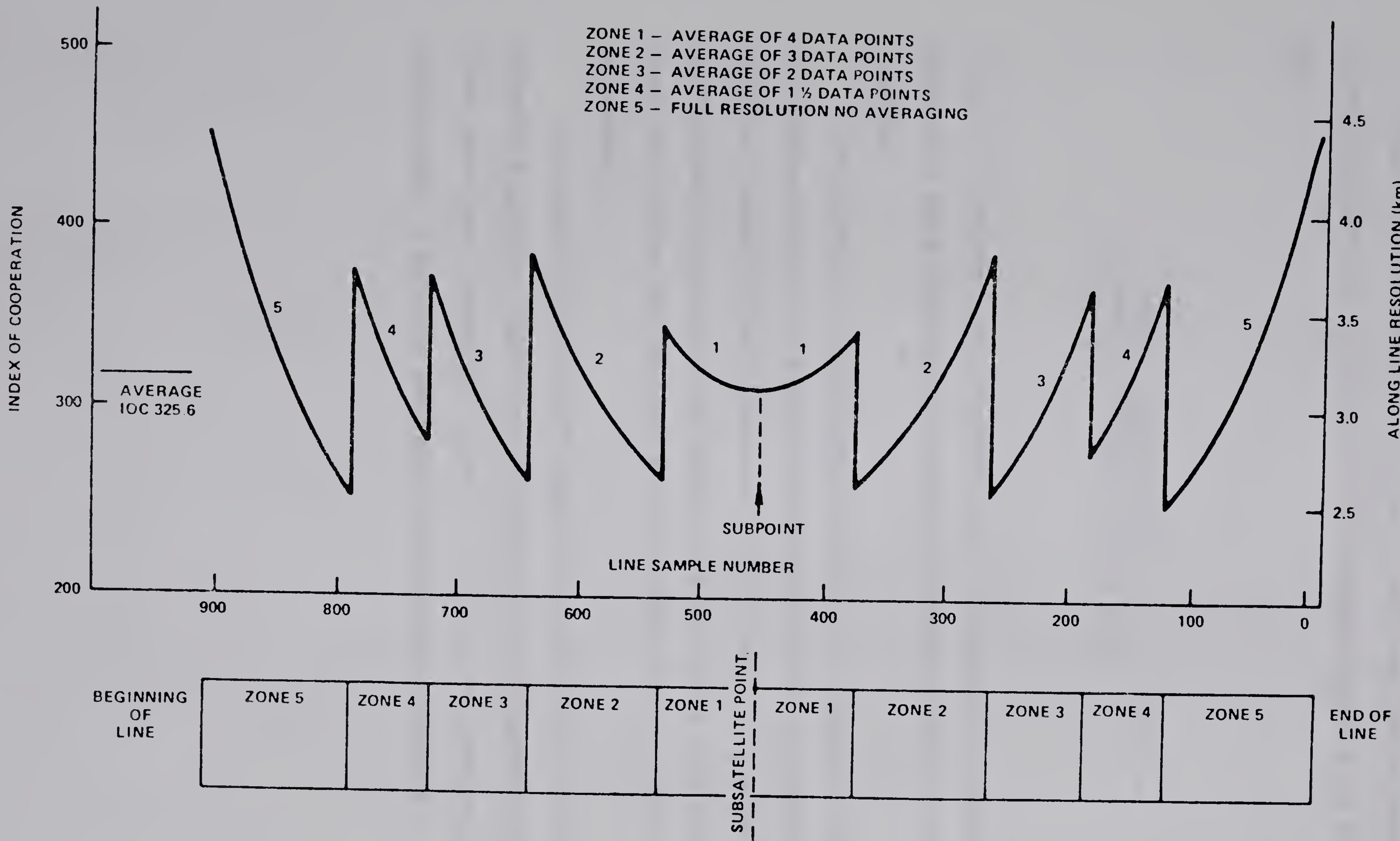


Figure 2.1 APT linearization regions and resolution. (after Schwalb, 1978)

2.3 Satellite Resolution

The TIROS–N APT data are corrected in such a way that the resolution is constant (4 km) along each scan. The distance between adjacent scans at the sub-point is given by,

$$\frac{360^0 * 111^0/km * 1.017}{102\ min/orbit * 2\ scans/min * 60\ s/min} = 3.31\ km$$

where 1.017 represents the conversion factor from geocentric to geodetic coordinates. Hence, each digital value recorded represents the radiance averaged over a 4 * 3.3 km rectangle.

The University of Alberta satellite laboratory is equipped to receive the analog APT signal and convert it to digital values between 0 and 255 at a digitizing rate of 2400 Hz. Visible reflectance represented on this scale generally ranges from 30 digital counts (ground and water) to 230 digital counts (thick cloud). Warm and cold emitting layers and surfaces are represented in the infrared by high and low digital counts, respectively.

The output rate for the APT digital data is 4160 "words" per second, or 1600 digital values per scan. The infrared and visible data are represented along a scan by 700 digital values each, leaving 200 values in each scan for synchronization pulses and telemetry data. A sample of one scan of data can be seen in Figure 2.2.

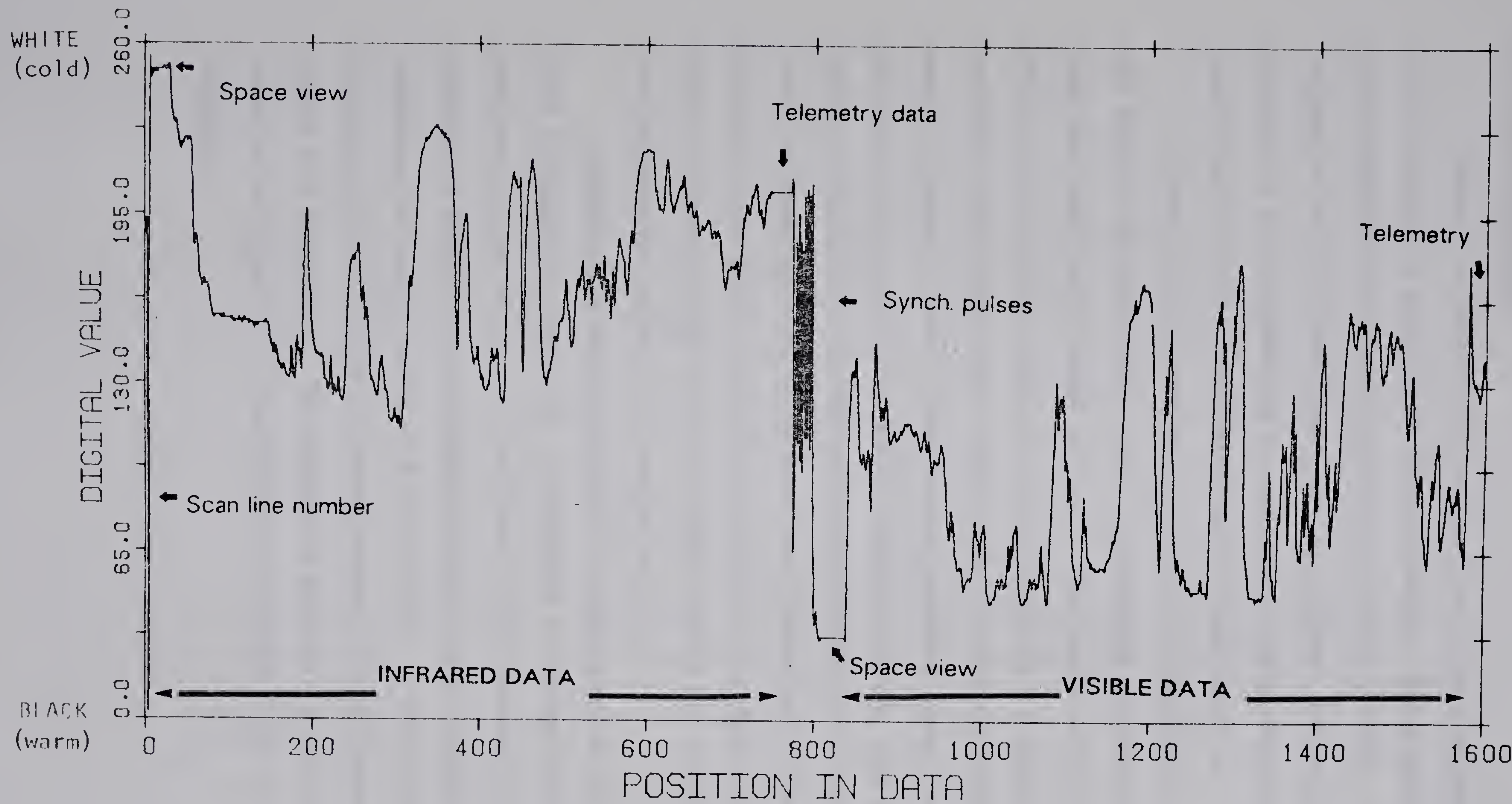


Figure 2.2 Example of one scan of TIROS-N APT data.

2.4 Internal Calibration

Calibration of the infrared channel of the AVHRR Is possible because the output of the instrument is almost linear with input energy. During every scan, the radiometer views space (0 radiance) and its housing (approximately 290°K). The housing has been designed to be a black body target, with four platinum resistance thermometers (PRT's) embedded in it. By determining the radiometer's output while viewing the housing and space it is possible to ascertain the instrument's response curve.

In order to calibrate the infrared channel, it is necessary to relate the recorded APT signal to the AVHRR data. This is accomplished by determining the relative signal level using eight grey "wedges" as a scale. The output from the space view, housing PRT's, and representative values of all the wedge levels are located between the infrared and visible data in each scan. Wedge values are cyclically repeated over eight scans every 128 scans. In order to determine representative wedge level values the telemetry data output from program TAPERED (Appendix C.2) was used as input for program TELEM (Appendix C.3). The mean and standard deviation of 160 values over eight scans were computed to give the wedge level value. Sample output from program TELEM can be seen in Appendix D. The original data level of the signal was then determined by taking the average wedge levels and relating them to the original wedge levels which were recorded before the satellite was put into orbit.

The relationship between the TIROS-N wedge levels and those recorded for orbit 3758 is displayed in Figure 2.3. A polynomial fit between these two data sets was performed by the MIDAS (Fox and Gutre, 1976) statistical package available at the University of Alberta. The coefficients obtained from this procedure were then used in determining the average temperature of the PRT's. A second polynomial fit was then performed in order to find the recorded University of Alberta value corresponding to the average PRT temperature. The discrepancy between the University of Alberta digital values and the digital values transmitted by the satellite is due to a digital-analog-digital conversion.

The University of Alberta receiver at Ellerslie, Alberta is slightly dependent on temperature; to account for this the amplitude of the recorded signal can be arbitrarily adjusted at recording time by the technician operating the satellite receiver. The averaging technique and polynomial fitting just described were used to eliminate any effects that varying signal amplitude and temperature might have on the recorded data.

Once the relationship between the onboard calibration wedge levels and those recorded at the University of Alberta is known, the infrared data may be calibrated to obtain the temperature field using the technique described in Appendix A.

It was found through a number of tests that this calibration routine was on average accurate to $3^{0}K$ in determining the temperature from the same digital count using different polynomial coefficients. However, on inspection of Figure 2.4, a plot of digital counts versus temperature for five different satellite orbits, one can see that in the worst case a single digital count may yield a temperature difference of up to $10^{0}K$. Hence, a separate polynomial fit is necessary for each orbit.

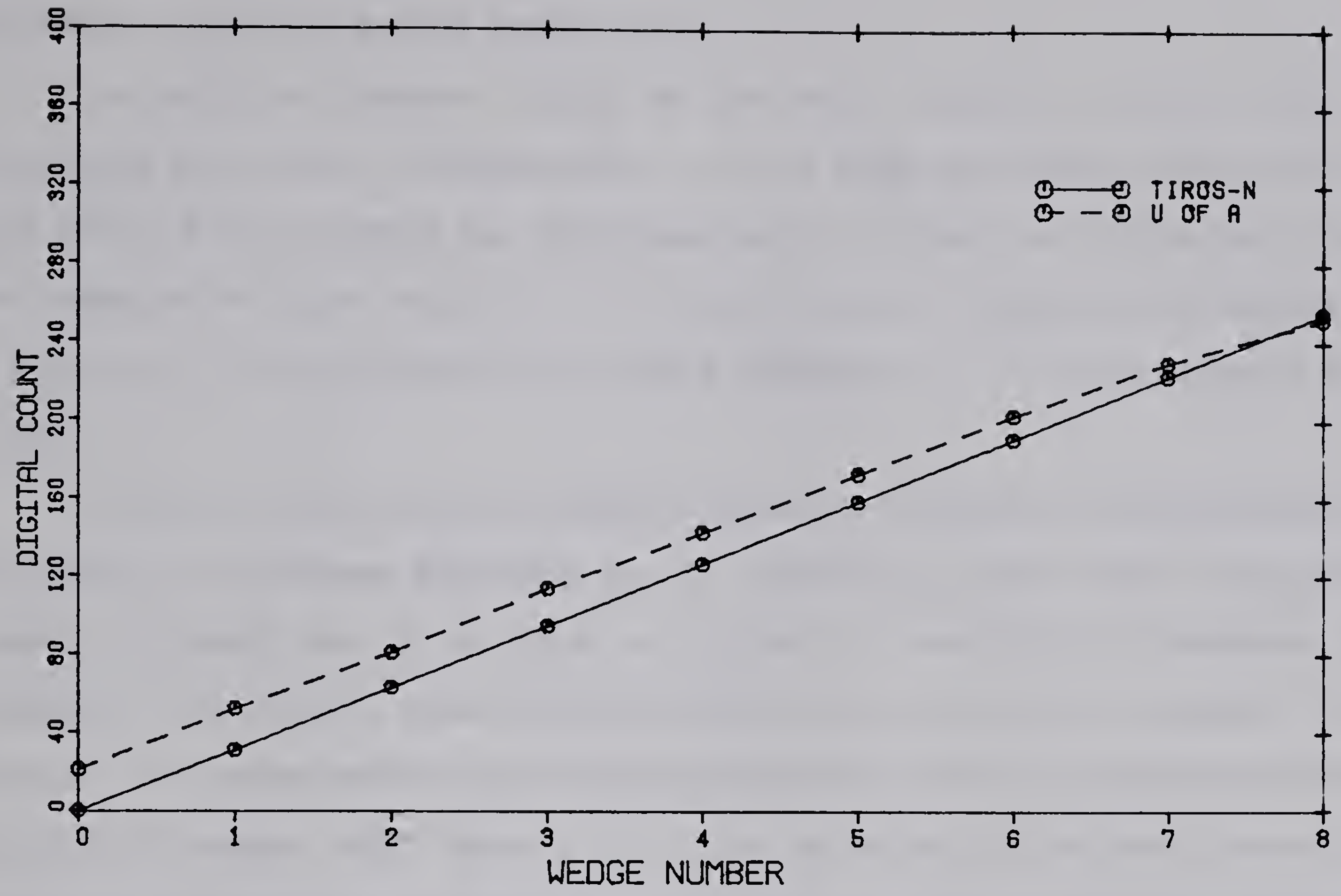


Figure 2.3 Relationship between TIROS-N transmitted wedge levels and those recorded at the University of Alberta.

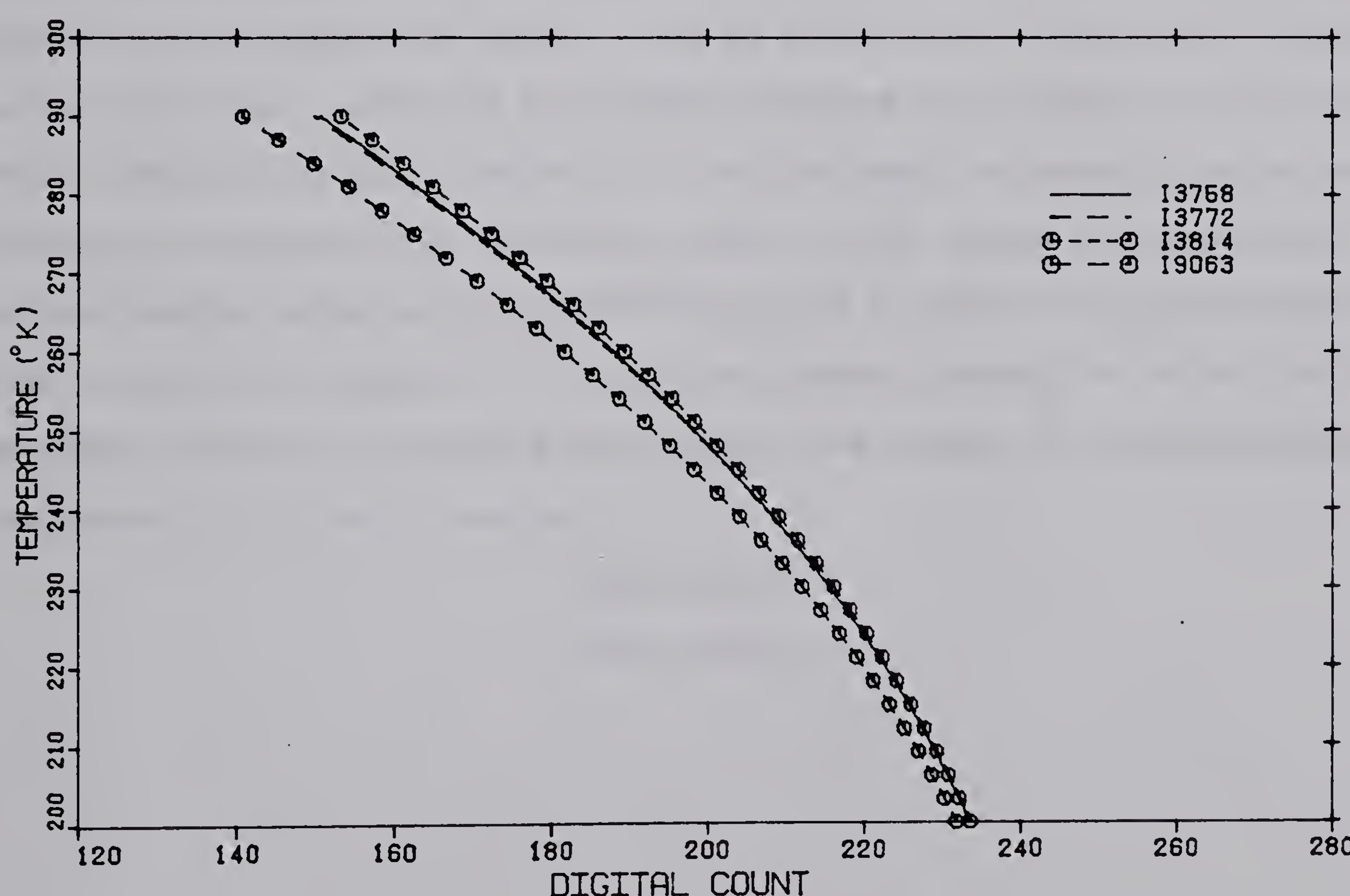


Figure 2.4 Temperature (°K) versus digitial count for five case studies.

2.5 Errors in Satellite-derived Temperatures

According to Schwalb (1978) the non-linear response of the AVHRR Is responsible for an error of approximately $-1.7^{o}K$ at $293^{o}K$ decreasing to $0^{o}K$ at $200^{o}K$. By a series of experiments it was determined that for a digital count difference of one, the calibration technique would, in the worst case, produce a temperature difference of $3^{o}K$ for very low temperatures ($200^{o}K$), and a difference of $1^{o}K$ for temperatures near $293^{o}K$.

Perhaps the most complex problem in deriving temperatures from satellite data is accounting for longwave attenuation due to absorption by water vapor and carbon dioxide. Although the 11 um band is a region of relatively little absorption by atmospheric constituents, under certain conditions this effect can be significant. For example, a moist atmosphere may attenuate the radiation emitted by the earth's surface by 5-10% (Weinreb, 1980). Because part of the thermal radiation emitted by the earth's surface is absorbed and re-emitted by the atmosphere, a radiant temperature measured from space will be lower than the true surface temperature. From experiments in the tropics Curtis and Rao (1969) estimated that at the satellite subpoint the brightness temperature measured by the satellite would be $2-4^{o}K$ colder than the actual radiating surface temperature. Since one would expect the water vapor content of the air over central Alberta (2200'-3500' msl) to be far less than that in the tropics, a conservative estimate of attenuation from the surface might be $2^{o}K$. Ideally, one should apply a radiative transfer model such as LOWTRAN (Selby et al., 1978) to the data available in order to determine attenuation. In lieu of this rigorous method, the worst case for atmospheric attenuation will set the error limits for the accuracy of the satellite-derived temperatures in this study. These are:

$\pm 3^{o}K$ at $200^{o}K$

$\pm 4^{o}K$ at $293^{o}K$.

3. Satellite Data Manipulation

3.1 Introduction

During the summers of 1979 and 1980 the University of Alberta satellite laboratory recorded a minimum of two satellite passes over Alberta every afternoon. Assuming no lack of satellite data the case studies for this investigation were chosen from the Alberta Research Council's Hail Project hail size index. Three days in July 1979 and one day in July 1980, when the hail size was walnut size or greater, were chosen for case studies. In this chapter the development and implementation of the cloud top temperature model used in this study are examined.

3.2 Identification of Study Area

A map of the study area including both geographical and political boundries can be seen in Figure 3.1. The area outlined in heavy black represents the Alberta Hail Project Area, and corresponds to the 80 mile range markers on the satellite contour and radar maps.

The topography of central Alberta is not characterized by any prominent surface features. Gently rolling hills and a few modest-sized lakes make visual identification of the study area by satellite data difficult even in the case of no cloud cover.

In order to eliminate the problems of no distinguishable land marks, or land marks obscured by cloud, Ormsby (1975) used gridded overlays of geographical and political boundaries. These overlays are calculated and drawn for specific satellite orbits and used for gridding all other orbits with similar characteristics. This method, although adequate for qualitative work, lacks the precision needed for quantitative work. A more accurate representation of latitude and longitude may be produced by calculating the latitude-longitude intersections from known satellite orbital parameters. These intersections can be transferred directly to satellite images in the form of fiducial marks (Reinelt et al., 1975).

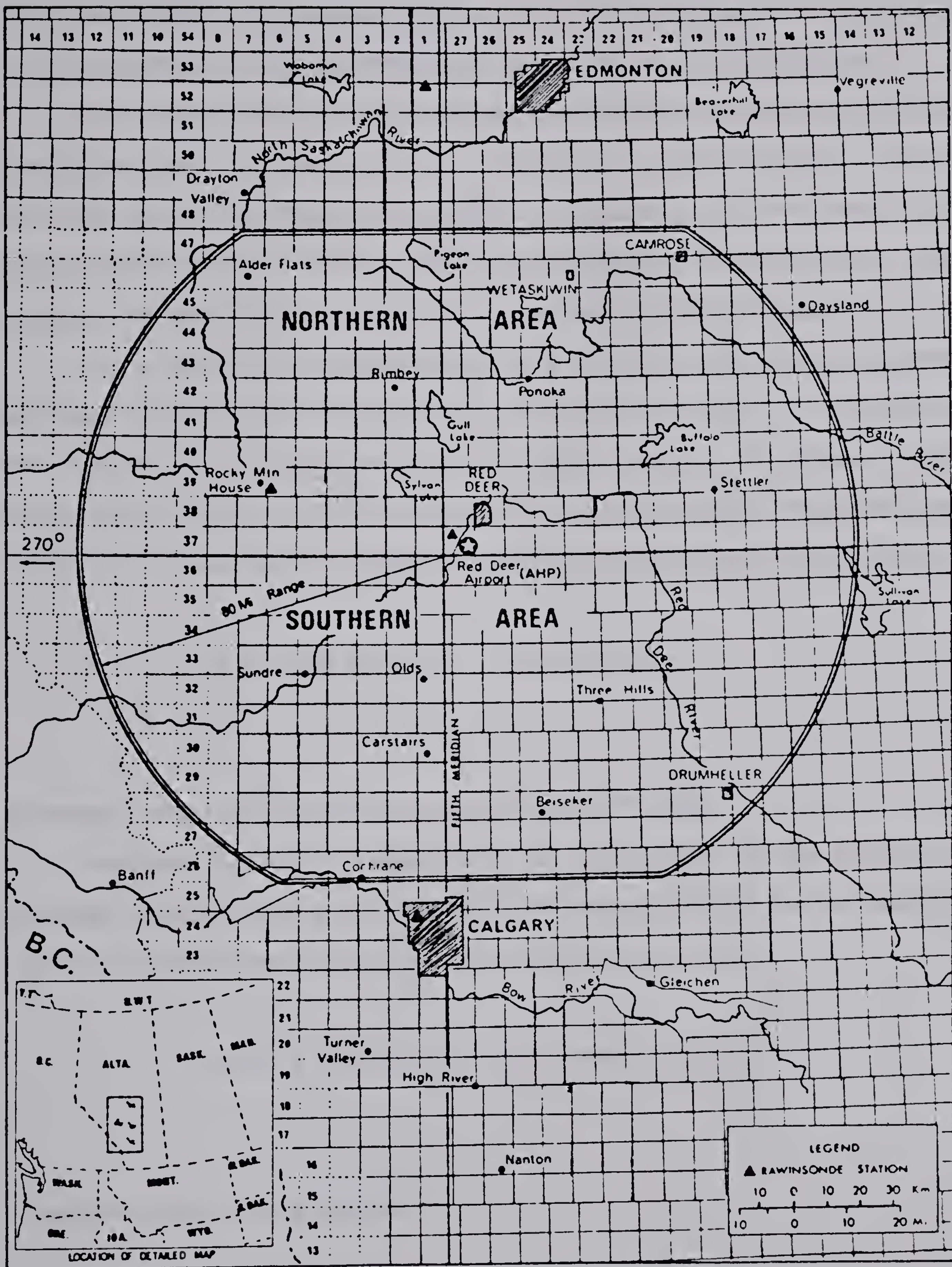


Figure 3.1 Alberta Hail Project Area. (after Deibert, 1979)

A combination of these two methods is used to correct the gridding errors for every satellite pass recorded at the University of Alberta. The pertinent information from this check is then recorded with the other orbital parameters, thus allowing for the accurate gridding of relatively small areas, such as the area around Penhold.

A variation of the scan-by-scan gridding procedure described by Reinelt et al. (1975) was used to produce the town site positions used in this study. The formulas used vary only in that they produce points on a geodetic (from the earth's foci) rather than geocentric (from the earth's center) grid. A listing of these equations is given in the computer program SCAN (Appendix C.1) and subroutine ITERA (Appendix C.4).

Since the TIROS-N satellite series has lower orbits than previous meteorological satellites, and their pitch, roll, and yaw are controlled within $\pm 0.1^{\circ}$, the gridding of their data is much more accurate than that of previous satellites. The largest gridding error discussed by Greaves (1980) is eliminated by using geodetic rather than geocentric gridding. The error due to variations in the satellite's attitude (pitch, roll, or yaw) is

$$\pm 0.1^{\circ} * 865 \text{ km} * 2 * \text{PI} / 360^{\circ} = \pm 1.5 \text{ km},$$

a variation which is less than the resolution of the APT signal.

Another source of gridding error is in the timing of the satellite's equator crossing. Since this time is only accurate to the nearest second, and the satellite requires 102 minutes to scan the circumference of the earth, an error of

$$\pm 0.5^{\circ} * 2 * 6367 \text{ km} * 6120 \text{ s/orbit} = \pm 3.2 \text{ km}$$

is possible at the satellite subpoint.

3.3 Data Manipulation

The four steps necessary for procuring cloud-top temperature plots in the manner used in this study are described below.

1) The orbital parameters for each case study were used in conjunction with program SCAN (Appendix C.1) to determine the maximum and minimum scan and position numbers defining a box covering central Alberta, as well as the positions of various town sites within a one hundred mile range of Penhold.

2) Using this information, program TAPERED was run in order to copy the satellite tape data inside this box to a copy tape, and to read the telemetry data over the area of interest, the calibration wedge levels were then obtained by running TELEM on this telemetery data.

3) Program SCAN was then rerun in order to smooth, calibrate (in the infrared case) and write the data field into a file. Subroutines SMOO and CALI can be seen in Appendicies C.5, and C.6 respectively.

4) These data were then output as either a contour or grey-level map using programs PLT or GREY, (Appendices C.7, and C.8 respectively).

The data field is smoothed by a simple three-point smoothing operation on the sides of the field, and a four-point smoothing operation in the interior of the field. It was found that two light smoothing operations resulted in the clearest representation of the temperature field while retaining all pertinent information. Noise lines and synchronization pulse problems were eliminated in the first smoothing operation by subtracting the smoothed from the unsmoothed fields, pixel by pixel. These differences were then summed up along each scan and the mean and standard deviation of each scan was computed. If the mean of any one scan was outside two standard deviations the scan was rejected and set equal to an adjacent scan.

The effects of this smoothing and noise elimination routine on the visible data from orbit 3758 can be seen in Figures 3.2, a and b. The mean and standard deviation, as well as the scan number rejected, were output in order to observe the effect of the smoothing. From inspection of these parameters (see SCAN output, Appendix B), one can see that the average temperature change due to smoothing is small when compared to the $\pm 3.0^{0}$K uncertainty of the temperature measurements discussed in Chapter 2.

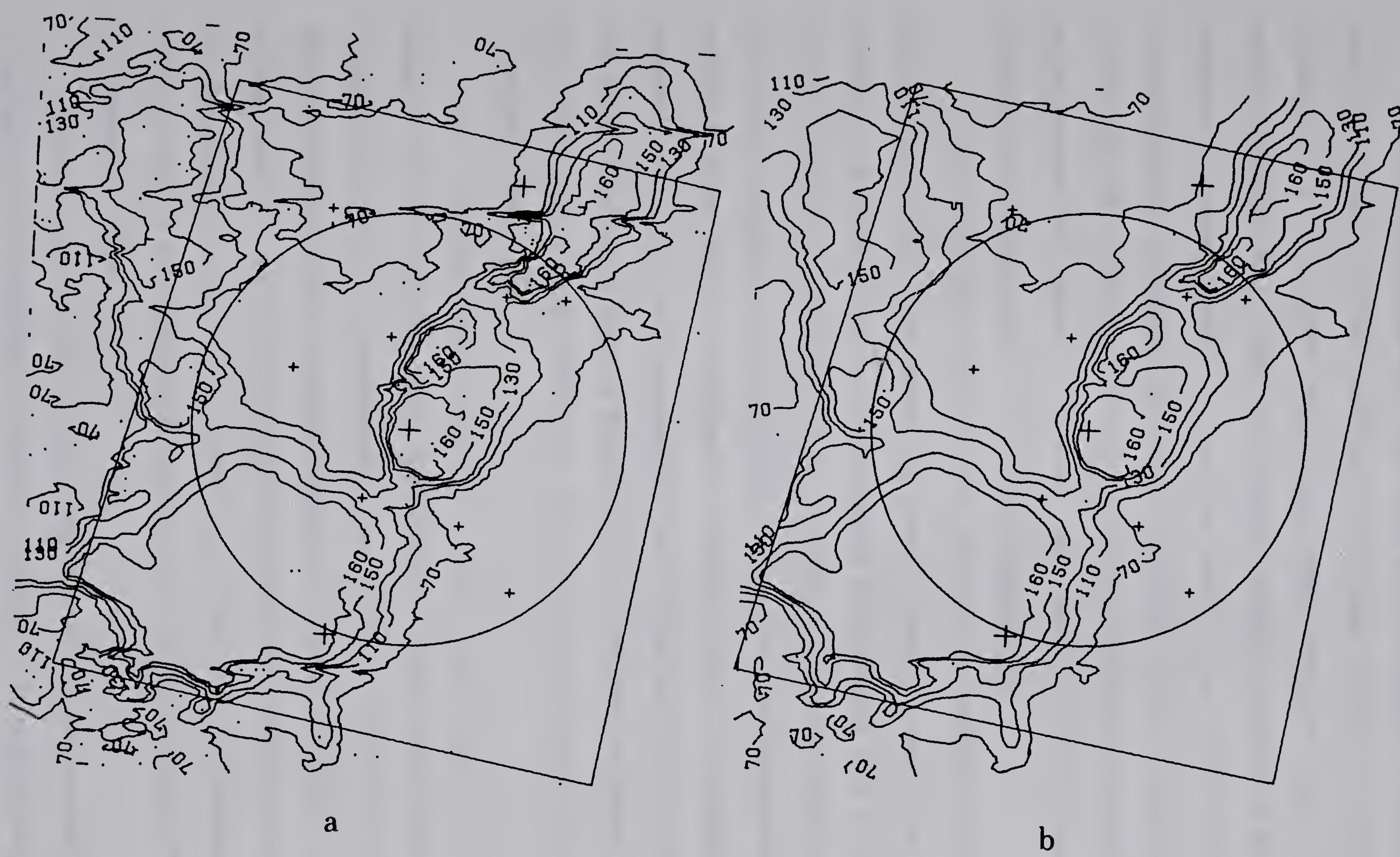


Figure 3.2 Visible imagery from orbit 3758
a) unsmoothed
b) smoothed.

3.4 Frequency Table Discussion

Satellite data, because of their large areal coverage, lend themselves easily to cloud classification methods. Early work in this area involved only visible-range imagery (Anderson et al., 1966, Aber and Taggart, 1969), then later both visible and infrared imagery (Anderson et al., 1969). More recent attempts to determine the spatio-temporal evolution of cloud patterns involve the use of only visible or infrared data in monodimensional histograms (Szejwach and DeBois, 1978). Reynolds and VonderHaar (1979) use both visible and infrared data in their "bi-spectral" method for determining cloud amount and height, while Harris and Barrett (1978) discuss the use of a brightness/texture approach for an objective nephanalysis.

In this study both visible data to detect cloud thickness and infrared data to determine cloud top temperature are used to classify cloud types. The concluding remarks of a review paper on rain estimates from satellite data, by Martin and Sherer (1973) support this combination of data: "Based on a bivariate frequency distribution of bright versus temperature, Gruber (1973) concluded that brightness enhancing or infrared technique alone might be inadequate to deduce details of convective activity." This statement reinforces some observations that the brightest part of the cloud may not be the coldest because of shear or the distribution of radiative properties of hydrometeors. This implies that a better estimate of cloud type may be made from a combination of visible and infrared data.

An objective determination of cloud type was accomplished by the implementation of program FREQ (Appendix D). Critical levels defining cloud borders were assumed to be 70 digital counts in the visible, and 0°C in the infrared data. Using this information the cloud frequency program simultaneously looks at both the visible and infrared data for each pixel and groups that pixel into a 5°C and 5 digital count "family." The percentage of each "family" is then output in the form of a frequency table.
Table 3.1 gives a description of the type of cloud found in the four different regions of the frequency Tables 4.2 to 4.6.

The frequency of the 5°C and 5 digital count groups were also output separately in histogram form (Appendix D) in order to determine the contour values and "slicing" in the digital plotting programs PLT and GREY.

Table 3.1 Frequency table description

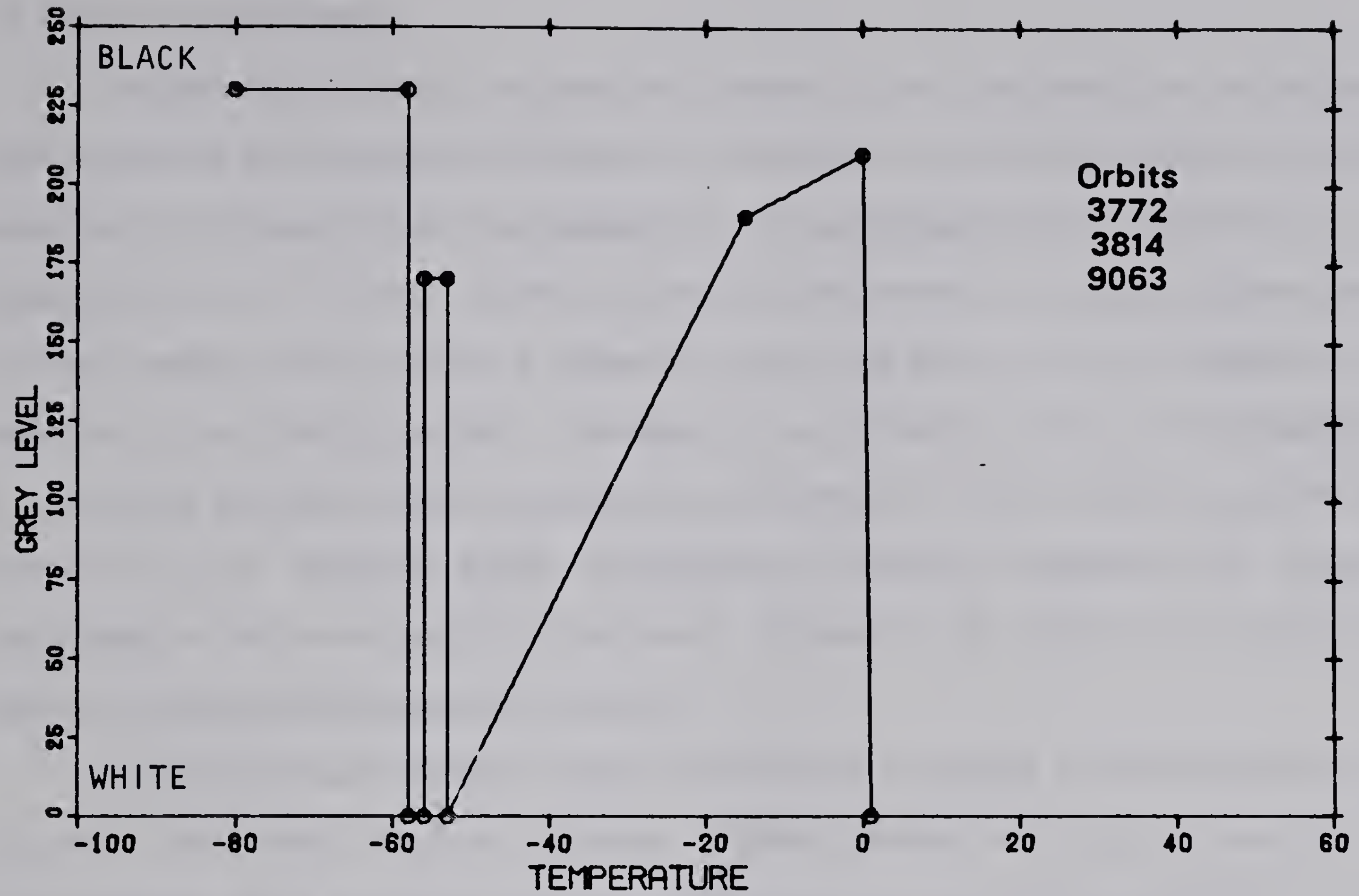
Region	Characteristics	Cloud Type
Upper left	very cold,high visible reflectance (great vertical extent)	cumulonimbus, towering cumulus
Lower left	very cold, low visible reflectance, (high thin layer)	cirrus, cirrostratus, cirrus anvil
Upper right	warm, high visible reflectance,(low thick cloud)	cumulus, stratocumulus
Lower right	warm, low visible reflectance, (low thin cloud)	stratus, fog

4. Thunderstorm Case Studies

4.1 Introduction

The characteristics of radar and radiosonde data and the problems of "ground truthing" satellite derived cloud-top temperatures with both of these will be discussed and illustrated in this chapter.

Contour maps of infrared and visible data for accurate geographical orientation, and grey-level, visible and sliced infrared data to emphasize cloud structure are presented for each case study. The locations of Edmonton, Penhold and Calgary are marked on the grey-shade maps by either a white or a black cross. Contour maps mark the locations of Edmonton, Calgary, Drayton Valley, Camrose, Wetaskiwin, Rimbey, Rocky Mountain House, Olds, Three Hills, and Drumheller as well as north-south, east-west cross hairs intersecting at Penhold. It may be noted that these cross hairs are not perpendicular; this is due to the fact that the earth is rotating under the satellite as it scans. The various infrared slicing algorithms determined from the frequency tables of the passes are displayed in Figure 4.1.



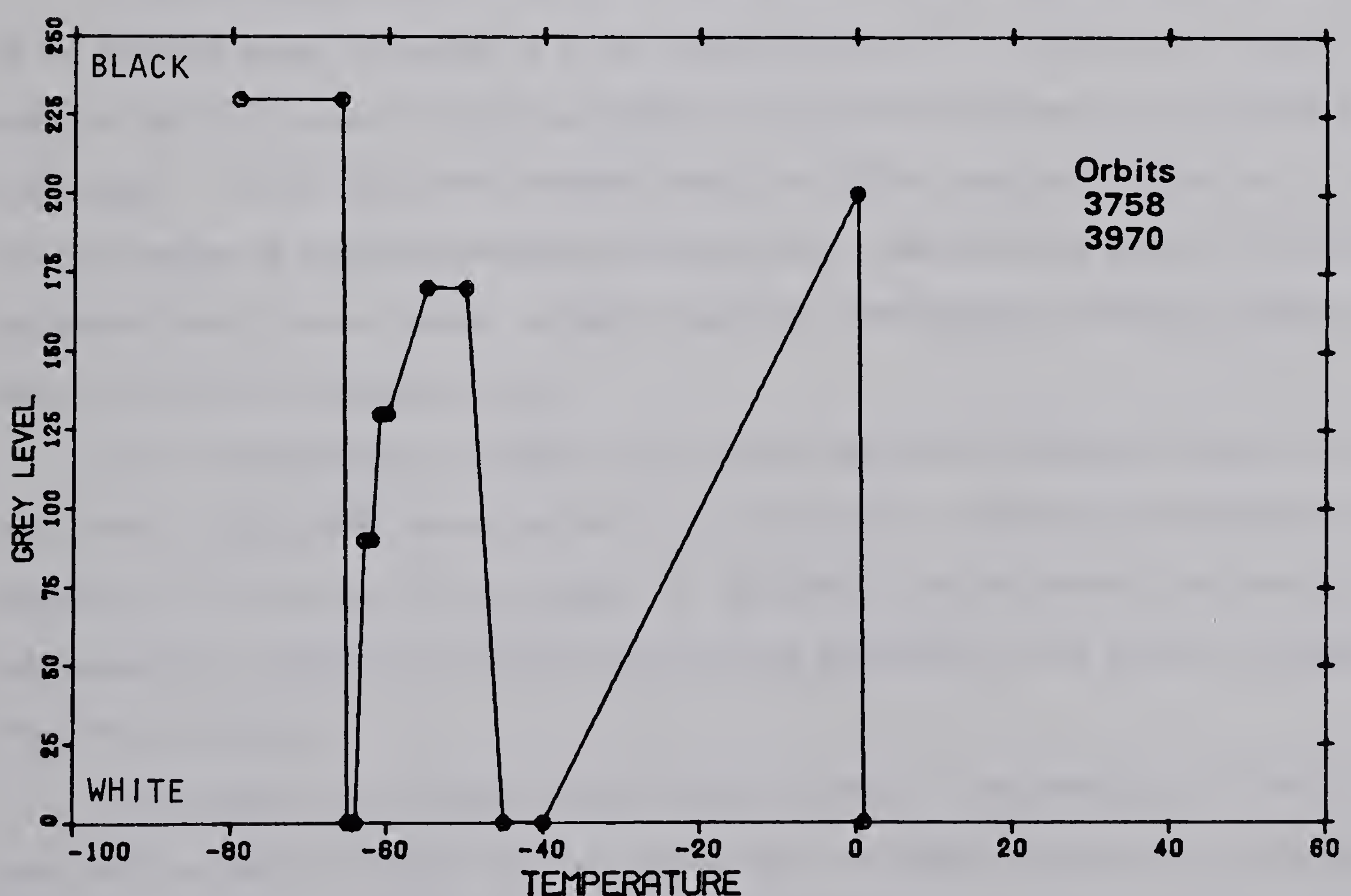


Figure 4.1 **Infrared slicing algorithims.**

4.2 Radar Characteristics

The detection of cloud droplets, rain droplets, snow, ice pellets and hail by radar (radio detection and ranging) has become an invaluable tool to meteorologists. Radar is based on the principle that an electromagnetic wave propagates along straight lines at the speed of light (3×10^8 ms^{-1}). Hence, by means of an antenna producing a narrow beam of radio energy and receiving a reflection from that beam, one can determine the direction of the reflecting object. The range of the reflecting object can be determined by recording the time interval between the transmission of the radio energy and the reception of its reflected signal. Hydrometeor detection capabilities are critically dependent on the wave length of the radar. In general, the smaller the particle, the shorter the wave length must be to detect it.

The Alberta Hail Project's S-band (10 cm) radar is capable of detecting raindrops and hail. The system's temporal resolution of three minutes and its spatial resolution of one kilometer make the study of thunderstorms within a one hundred kilometer range possible (Chisholm and Renick, 1972).

The radar data used in this study correspond in time with the satellite's scanning of the Penhold area. However, in a few cases (orbits 3772, 3814), there were brief breaks in the radar data, in which case radar data closest to the time of the satellite pass were used. The low-level Plan Position Indicators (PPI's) used for comparison of rain areas in Chapter 5, and the maximum echo tops used in sections 4.5 and 4.6 to estimate cloud-top height were readily available from the Atmospheric Sciences Department (ASD) of the Alberta Research Council.

Direct comparison of satellite and S-band radar data is difficult largely because radar views only a small cross-section of a cloud and is sensitive to precipitation size particles (> 0.1 mm), not cloud droplets (4–100 μm), while the satellite data consist of reflectance and radiance from cloud droplets and precipitation size particles measured from the cloud-top.

The height of the highest echo during the time of the satellite pass was taken from ASD output, this height was then compared to the height derived from the satellite temperature estimate and the radiosonde ascent in the area.

Accurate determination of cloud height by radar is difficult because the echo top does not necessarily coincide with the visible cloud top. Radar estimates of cloud top are dependent on both the beam width of the radar and the range of the target. Saunders and Ronne (1962) in their study of simultaneous measurements of convective cloud by theodolite and radar, found that in almost every case the radar beam gave a higher elevation angle than the theodolite when looking at the same cloud turret. They found that by subtracting a height increment equal to one-half the beam width (a) times the range (R) from the radar echo top, the height of the visible cloud exceeded the height of the "corrected" echo top. Figure 4.2 is an illustration of this error. Taking the radar range to be 130 km (80 miles) and the beam width to be 1.1° may yield an error of 1.2 km in the estimation of the height of the echo.

$$E_r = 0.5 * R * \sin(a)$$

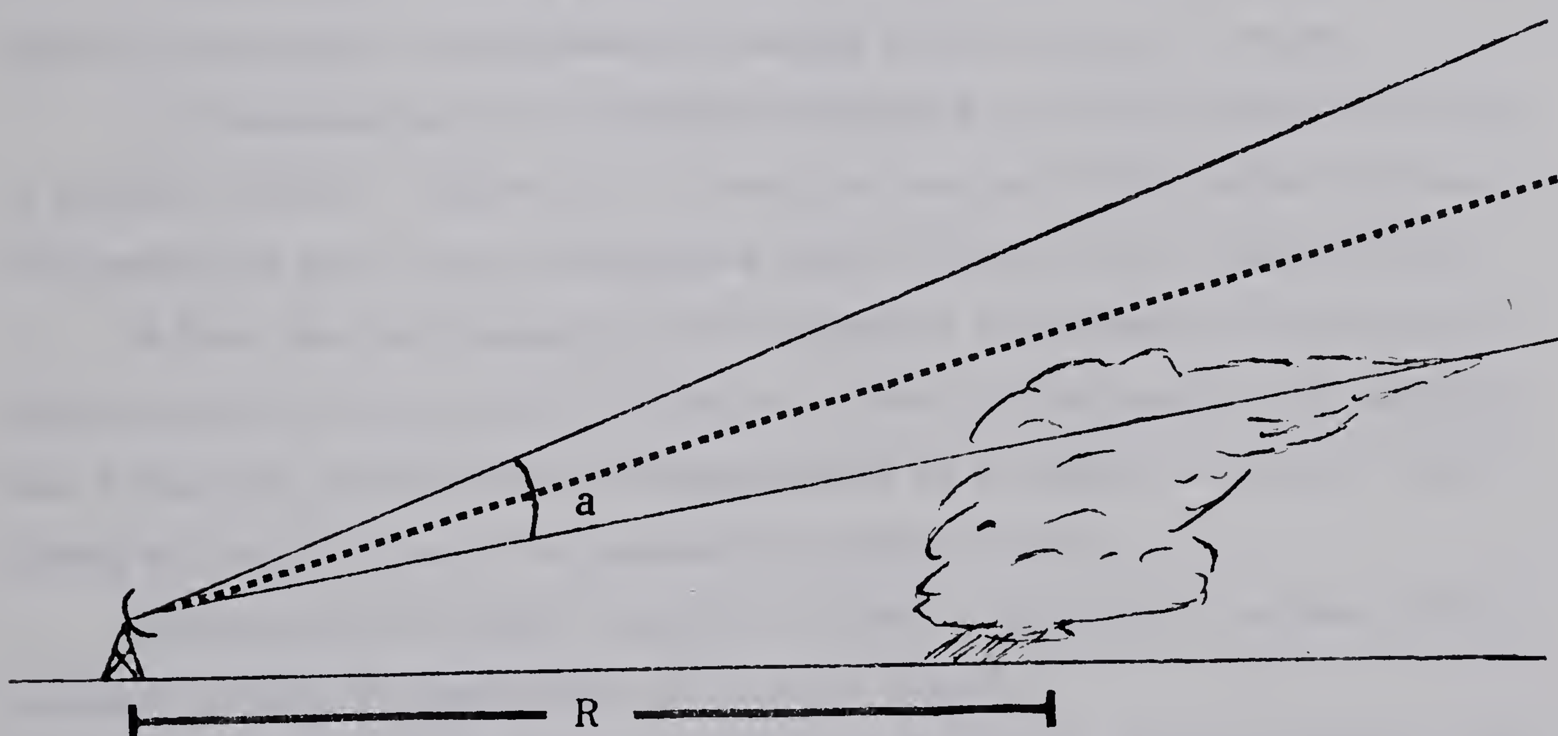


Figure 4.2 Illustration of error in deriving cloud top measurements with radar.

4.3 Convective Cloud Top Estimates from Radiosonde Data

Convective cloud-top temperature estimates from radiosonde data close to the time of a satellite pass were made in each of the case studies discussed in this section.

A schematic representation of the radiosonde data is plotted on a tephigram for each case study. The temperature and moisture profiles are represented on the tephigram by a solid and dashed line, respectively. The convective condensation level and the pseudo-adiabatic line are represented by a dotted line.

The normal procedure for estimating cloud-top temperature is to find the convective condensation level of the airmass and follow a line representing moist adiabatic ascent through the atmosphere until it crosses the environmental temperature curve, usually at the tropopause inversion. The convective condensation level is found at the intersection of the constant mixing ratio line leading up from the surface wet-bulb temperature, and a dry adiabatic line up from the surface temperature at the time convection was initiated.

There are several limitations to the procedure described above:

1) Radiosonde estimates of cloud-tops are point measurement, whereas the satellite-inferred value is representative of average conditions over a 4 km^2 area.

2) A representative surface wet-bulb temperature is difficult to obtain in the case of scattered showers. Determination of the cloud-base height from aircraft eliminates this problem and gives a more representative value of the convective condensation level.

3) Since standard radiosondes are not designed for release into thunderstorms, possible instrument error must be considered. Washout of the humidity duct, restricted flow through the humidity duct, and inaccuracies in the unshielded thermometer due to wetting and icing are a few of the possible instrument problems.

4)Variable balloon ascent rates due to updrafts, downdrafts, and icing further complicate the accurate determination of cloud-top heights.

Instrument and time resolution problems aside, another area of concern is the local modification of the atmosphere by thunderstorms. Davies-Jones and Henderson (1973), in their study of 33 different high plains thunderstorms found that the soundings taken in the updrafts of thunderstorms tended to be about 5°C warmer than the environmental soundings. From this it may be concluded that in a strong updraft, warm,

moist air ascends virtually undiluted, therefore modifying the tropopause in the vicinity of the thunderstorm. However, radiosondes are used operationally to yield a first guess at the cloud top height despite this local modification of the tropopause, instrument problems, graphical inacurracies and positioning problems.

4.4 Estimation of Energy Available for Tropopause Modification

The energies available for local modification of the tropopause were calculated for each case study. These energies were computed graphically from a representative tephigram using the parcel method. The results of these calculations are displayed in table 4.1.

From inspection of the large vertical velocities in table 4.1 it is obvious that the parcel method is inadequate for the determination of energies in a thunderstorm. The parcel method is very sensitive to the computed area between the temperature profile displayed on the tephigram and the moist adiabatic line describing the saturated parcel's ascent through the atmosphere. This area can be altered siginificantly by a small graphical error or a poor estimation of the cloud–base height.

The assumption made in deriving the vertical velocity from the energy was that all the bouyant energy available in the cloud is transformed into kinetic energy of vertical motion. Clearly this is not so; the average vertical velocity determined by this method was about 50 ms^{-1} (100 mph). A reasonable vertical velocity as measured by aircraft might be close to 20 ms^{-1} (Musil, et al., 1976). The parcel method is simplified as it does not contain any terms accounting for low level mixing, entrainment of dry enviromental air, nor viscous drag.

Even if the values in table 4.1 are asumed to be 100% too large because of the assumptions involved in their computation, one can see that these numbers are still indicative of severe thunderstorms. One interesting point about these rough estimates is that they are consistent relative to one another, that is, the larger and colder of these storms as indicated by the contour plots (Figures 4.10, and 4.18), Cases #1 and #4, have larger energies, and hence greater vertical velocities.

Table 4.1 Energy estimation from parcel method.

Storm	Energies jkg^{-1}	Vertical Velocities ms^{-1}
Case #1 July 6, 1979 CYYC	1570	56
Case #2 July 7, 1979 CYEG	1457	54
Case #3 July 10, 1979 CYRM	1240	50
Case #4 July 21,1979 CYEG	3245	80
Case #5 July 16, 1980 CYRM	1050	46

4.5 Ground-truthing on a Stratiform Day

In order to avoid the instrument icing and tropopause modification problems discussed in section 4.3, the cloud-top temperature model was run and verified on a day in which most of the cloud was stratiform.

The synoptic situation on the afternoon of July 11, 1979 was characterized by a surface low-pressure system just to the north-east of Edmonton. No hail reports were received on an afternoon dominated by stratus, altocumulus, and stratocumulus clouds, and light rain showers.

Satellite orbit number 3828 scanned over the study area at approximately 2130Z. The radiosonde ascent through the cloud deck for the 2200Z sounding at Penhold (CYQF) [1] yielded a cloud-top temperature estimate of $-12^{\circ}C$ at a height of 5.1 km (16,500 ft). Although the exact position of the balloon as it broke through the cloud is in doubt, one can see from Figure 4.3 that the area over Penhold was largely covered by cloud with temperatures between -10 and $-20^{\circ}C$.

Radiosonde ascents from Edmonton (CYEG) [2], Calgary (CYYC), and Rocky Mountain House (CYRM), all yielded cloud-top temperature estimates close to those expected from the satellite-derived temperatures. The time-integrated maximum echo top map for this period indicated a cloud-top of 3.4 to 4.6 km (11,000–15,000 ft), just under the estimates from both the satellite and radiosonde data.

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[1]The correct identifier for the Penhold (Red Deer Airport) upper air station is CYAF as of August 1981.
[2]The correct identifer for the Edmonton (Stony Plain) upper air station is CWSE as of August 1981.

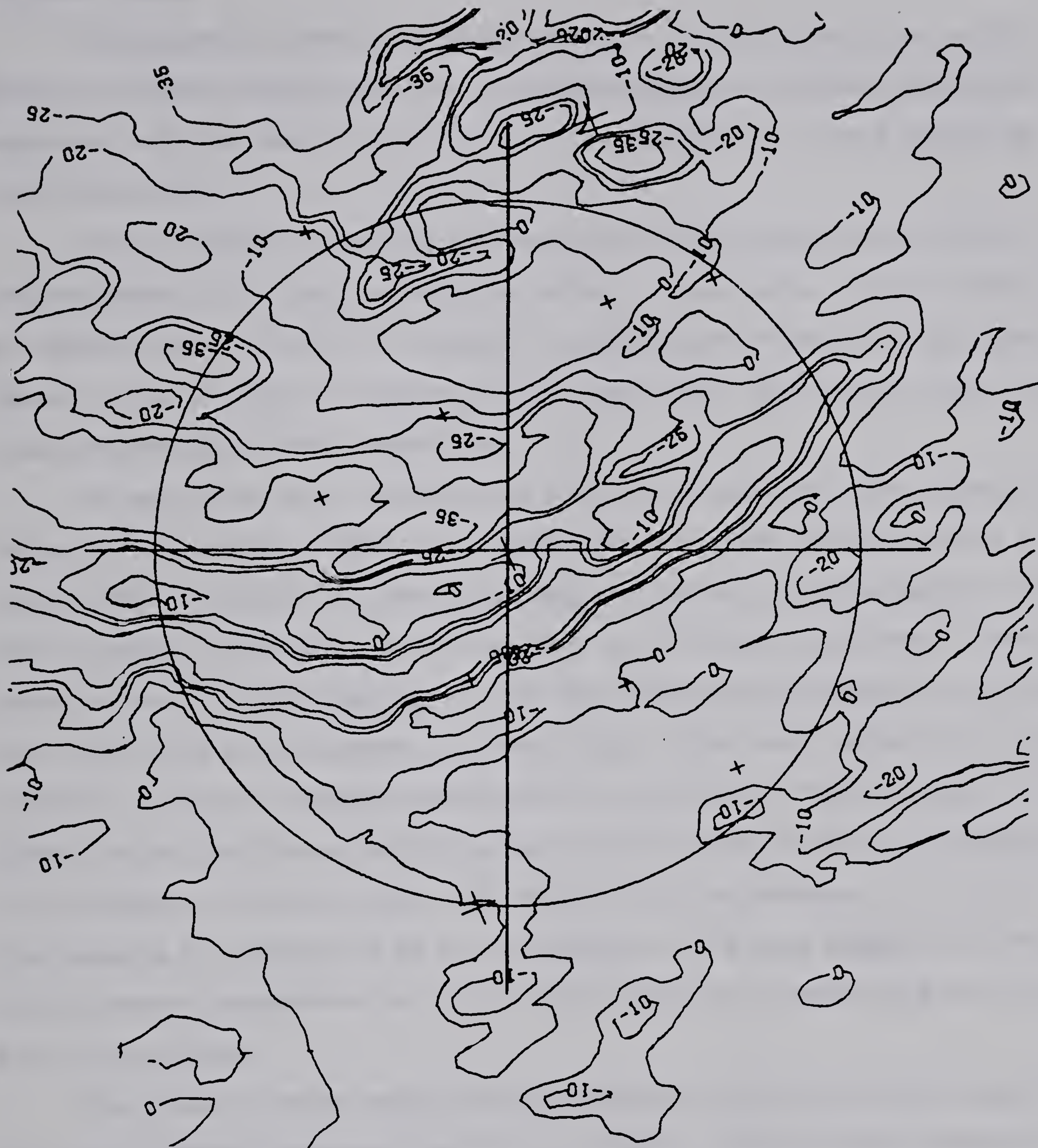


Figure 4.3 Infrared derived temperatures (°C) from TIROS-N orbit 3828.

4.6 Case Studies

The discussion of each case study includes: 1) a 500-mb height and vorticity analysis for 2400Z (1800 MDT); 2) two representative upper air soundings displayed on tephigrams, with the winds of one plotted on a hodograph; 3) a surface analysis for 2400Z (1800 MDT).

The solid isopleths on the 500-mb analyses are height contours in 60 m intervals, with the centers of the low's and high's marked by a crossed circle. Dashed isopleths are relative vorticity at $2*10^{-5}$ s^{-1} intervals. The maximum and minimum vorticity values relevant to the discussion are shown with an open circle. Short-wave ridges and troughs are indicated by heavy dashed lines.

For each case study soundings are shown from the radiosonde ascents at Penhold (CYQF), and one at either Rocky Mountain House (CYRM), Edmonton (CYEG), or Calgary (CYYC). The choice of a second sounding was made by considering which of the above locations would be more representative of the storm environment. These soundings show dry bulb (solid line) and wet bulb (dashed line) temperatures, and the moist adiabat that best represents a particular storm. Each moist adiabatic line was derived from values of maximum temperature and a mixing ratio. The mixing ratio was obtained by averaging the wet bulb temperature over the lowest 75-mb of the sounding. Two estimates of cloud-top height were derived from the tephigrams. The first of these assumes the cloud-top to be at the intersection of the moist adiabatic curve and the environmental temperature curve; the second estimate was obtained using the equal area or parcel method.

In an attempt to adjust cloud top height estimates to the current synoptic situation the "Wieler Standard Atmosphere" (WSA) was conceived. The WSA approximates the change in the height of the 250-mb surface based on the current 500-mb map. The adjustment to the 250-mb height from the standard atmosphere is taken to be twice the difference between the observed height of the 500-mb surface and the standard 500-mb height. This adjustment was used in all cloud top height estimates made in this study, except those derived from radar data.

4.6.1 Case Study #1 July 6, 1979

The synoptic situation the afternoon of July 6, 1979 was dominated by a long-wave trough at 500-mb sitting off the coast of Oregon. The 500-mb flow was diffluent over central Alberta, and surface winds were light (Figure 4.4). Prior to a short-wave ridge passage from the southwest at 2400Z several severe thunderstorms broke out. The convective day category (CDC) was 4 (walnut size), and 246 cases of hail were reported with a median time of 2345Z.

From figures 4.5a and 4.5b, the contoured infrared and visible images from orbit 3758 (2214Z), it is evident that at least three cells existed at this time, aligning themselves in a NE-SW line with the most vigorous cell just west of Calgary. Figures 4.6a and 4.6b, are grey shade representations of the visible and infrared fields respectively.

Figure 4.5a indicates that the storm to the west of Calgary had a minimum top temperature of −66°C (12.6 km), and a large anvil area colder than −55°C. The 0000Z radiosonde ascent at Calgary (YYC) (figure 4.7b) indicated cloud-tops at −56°C (11.7 km), (parcel method −70°C, 13.4 km). The 2000Z ascent at Penhold (YQF) (figure 4.7a) gave an estimate of cloud-tops at −60°C (12.2 km). Assuming these to be representative of the environmental air at 2130Z one might infer that overshooting cloud turrets had locally modified the tropopause by 0.5 km, creating a "convective bulge". The maximum echo top at this time over Calgary was estimated from figure 4.8 to be 12.6−13.8 km (41−45,000 ft).

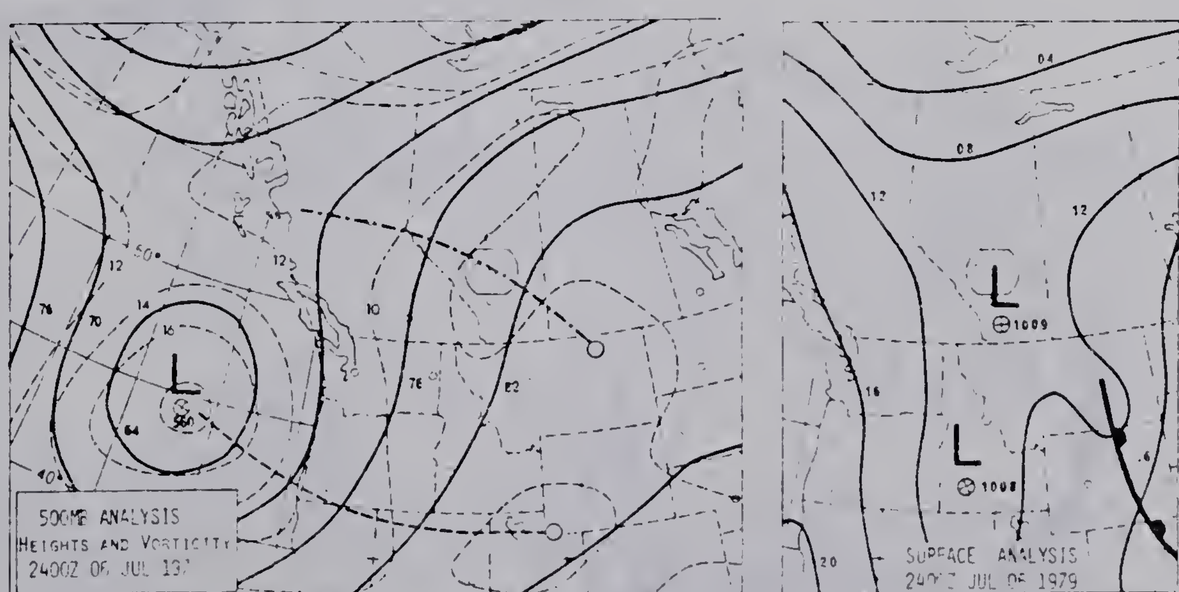
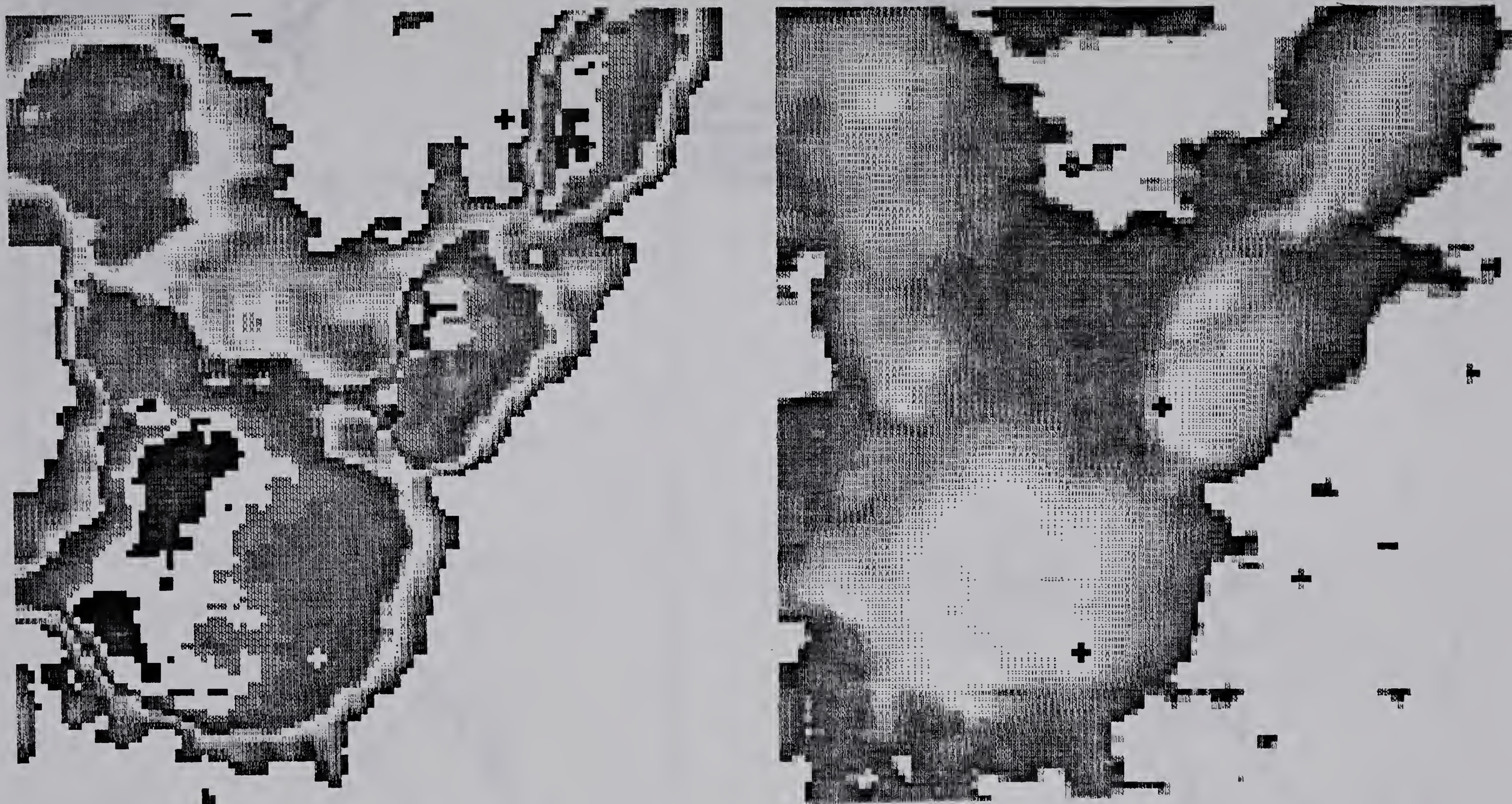


Figure 4.4 500-mb and Surface maps July 6, 1979

Figure 4.5 Contoured image from TIROS-N orbit 3758

a) Infrared, b) Visible.



a b

Figure 4.6 Grey level image from TIROS-N orbit 3758

a) Infrared, b) Visible.

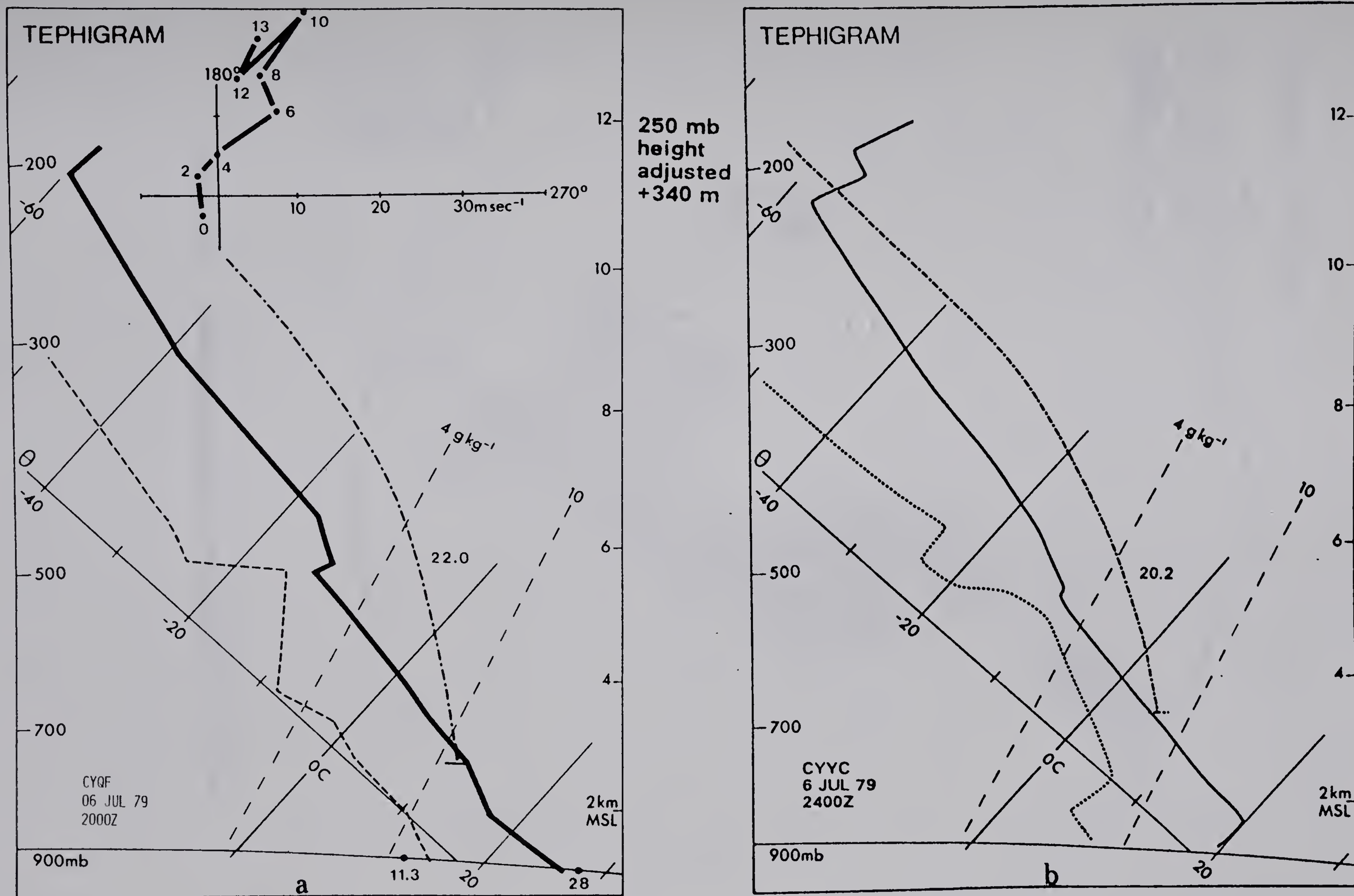


Figure 4.7 Tephigrams of radiosonde ascents, a) CYQF, b) CYYC.

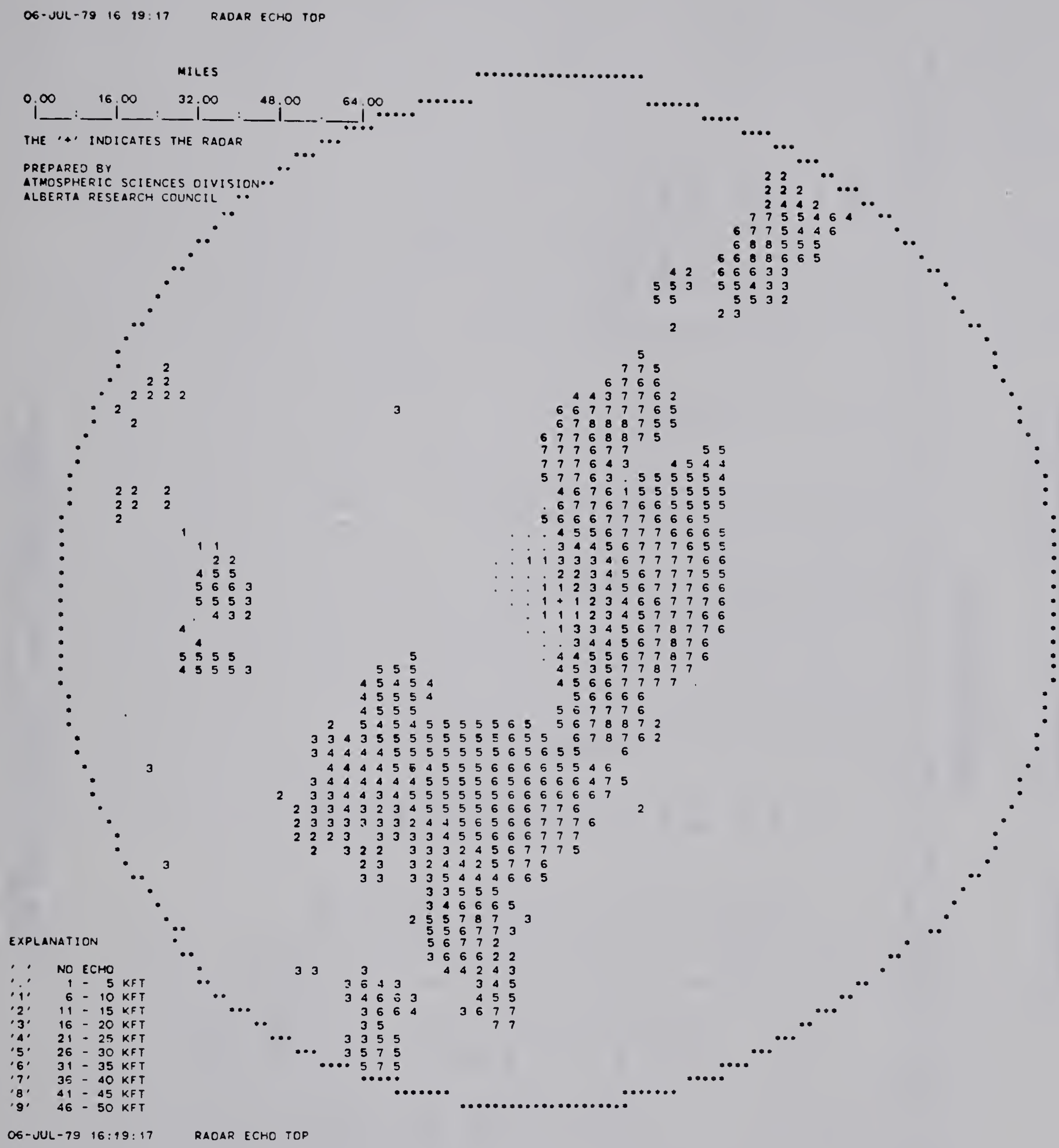


Figure 4.8 Maximum echo top map 2219Z July 6,1979.

VALUES GIVEN IN PERCENT OF TOTAL CLOUD COVER
54.0% CLOUD COVER OVER 39562. SQUARE KILOMETERS

Visible Reflectance \ Temperature (°C)	-70. to -65.	-65. to -60.	-60. to -55.	-55. to -50.	-50. to -45.	-45. to -40.	-40. to -35.	-35. to -30.	-30. to -25.	-25. to -20.	-20. to -15.	-15. to -10.	-10. to -5.	-5. to 0.	0. to 5.
175–180															
170–175	1.0	4.0	1.0												
165–170	2.4	3.6	1.1												
160–165	1.7	2.1	1.8	0.2											
155–160	1.1	2.5	1.9	1.0	0.3										
150–155	0.5	1.6	1.8	1.5	0.4										
145–150	0.4	1.4	1.5	1.5	0.7	0.3	0.1								
140–145	0.4	1.1	0.9	1.6	0.8	0.6	0.2								
135–140	0.3	1.0	0.6	1.2	1.0	0.5	0.3								
130–135	0.4	0.6	0.6	1.0	0.9	0.5	0.4	0.3	0.1						
125–130	0.1	0.5	0.5	0.7	0.7	0.5	0.2	0.3	0.2						
120–125		0.3	0.3	0.5	0.6	0.5	0.4	0.3	0.2	0.1	0.2				
115–120		0.2	0.3	0.5	0.6	0.5	0.4	0.3		0.2	0.2	0.1			
110–115			0.3	0.4	0.3	0.6	0.4	0.3	0.3	0.1	0.3				
105–110			0.4	0.5	0.4	0.4	0.3	0.3	0.3	0.2	0.4	0.1	0.1	0.2	
100–105				0.5	0.6	0.3	0.4	0.4	0.4	0.3	0.2	0.3	0.2	0.2	0.2
95–100				0.3	0.4	0.8	0.5	0.3	0.4	0.3	0.4	0.3	0.3	0.1	0.2
90–95					0.2	0.6	0.8	0.6	0.5	0.4	0.3	0.3	0.4	0.3	0.2
85–90						0.3	0.5	0.8	0.5	0.6	0.5	0.5	0.5	0.3	0.3
80–85							0.3	0.8	0.7	0.6	0.6	0.5	0.6	0.5	0.5
75–80								0.1	0.7	0.8	0.6	0.7	0.7	0.6	0.6
70–75										0.2	0.3	0.5	0.4	0.8	0.6

Visible Reflectance (vertical axis: 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 125, 130, 135, 140, 145, 150, 155, 160, 165, 170, 175, 180)

Temperature (°C) (horizontal axis: -70., -65., -60., -55., -50., -45., -40., -35., -30., -25., -20., -15., -10., -5., 0., 5., 10.)

Table 4.2 Frequency table for orbit 3758.

4.6.2 Case Study #2 July 7,1979

The general synoptic situation on the afternoon of July 7,1979 was characterized by the passage of a short-wave trough-ridge pair. The 500-mb flow was diffluent from the southwest, while the surface winds over central Alberta were from the northwest (figure 4.9). The CDC was 4, and 143 cases of hail with a median time of 2300Z were reported.

Figures 4.10 and 4.11 are the contour and grey level maps for orbit 3772 which scanned over Penhold at 2218Z. At this time the major storm in the study area consisted of two cells, one to the west of Wetaskiwin, and the second more vigorous one to the northwest of Edmonton.

Looking at the tephigram figure 4.12a for the 2000Z ascent at CYQF yields a cloud-top estimate of −52°C (11.1 km). The tephigram for the 0000Z ascent at CYEG (figure 4.12b) yields an estimate of −55°C (11.5 km), (parcel method −68°C, 13.3km). The radar maximum echo top map for the storm near Wetaskiwin gives a height of 11.1−12.3 km (36−40,000 ft). The cloud-top temperature of the cell west of Wetaskiwin as derived by satellite is −55°C (11.5 km). The data were contoured at −58°C, and −60°C, as the cell northwest of Edmonton shows, hence the −55°C estimate is not an artifact of the contour levels.

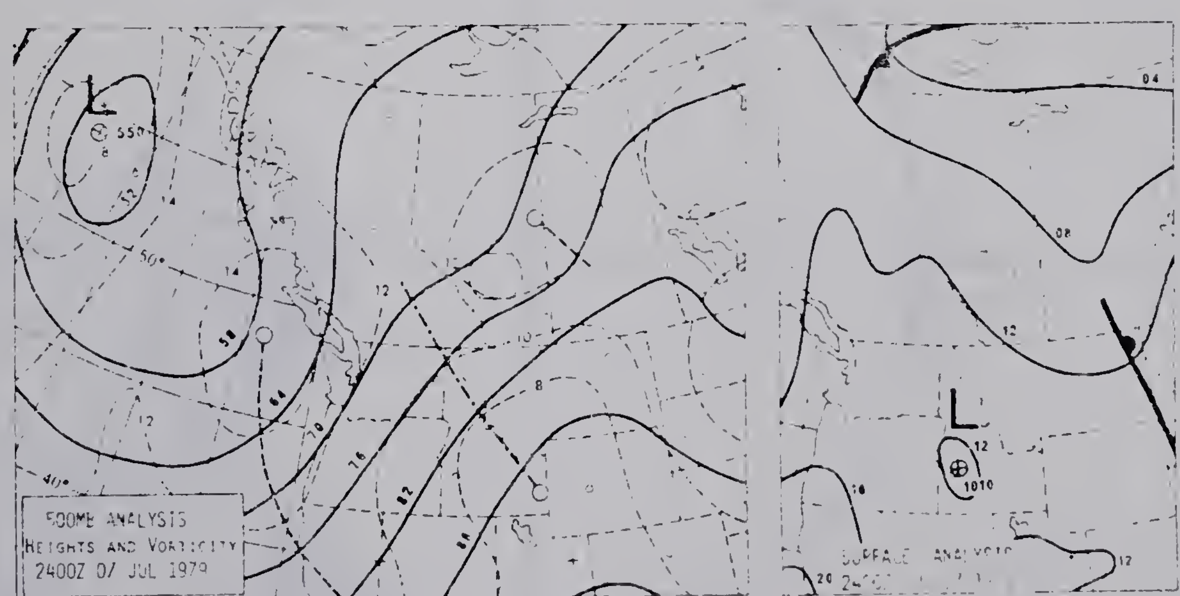
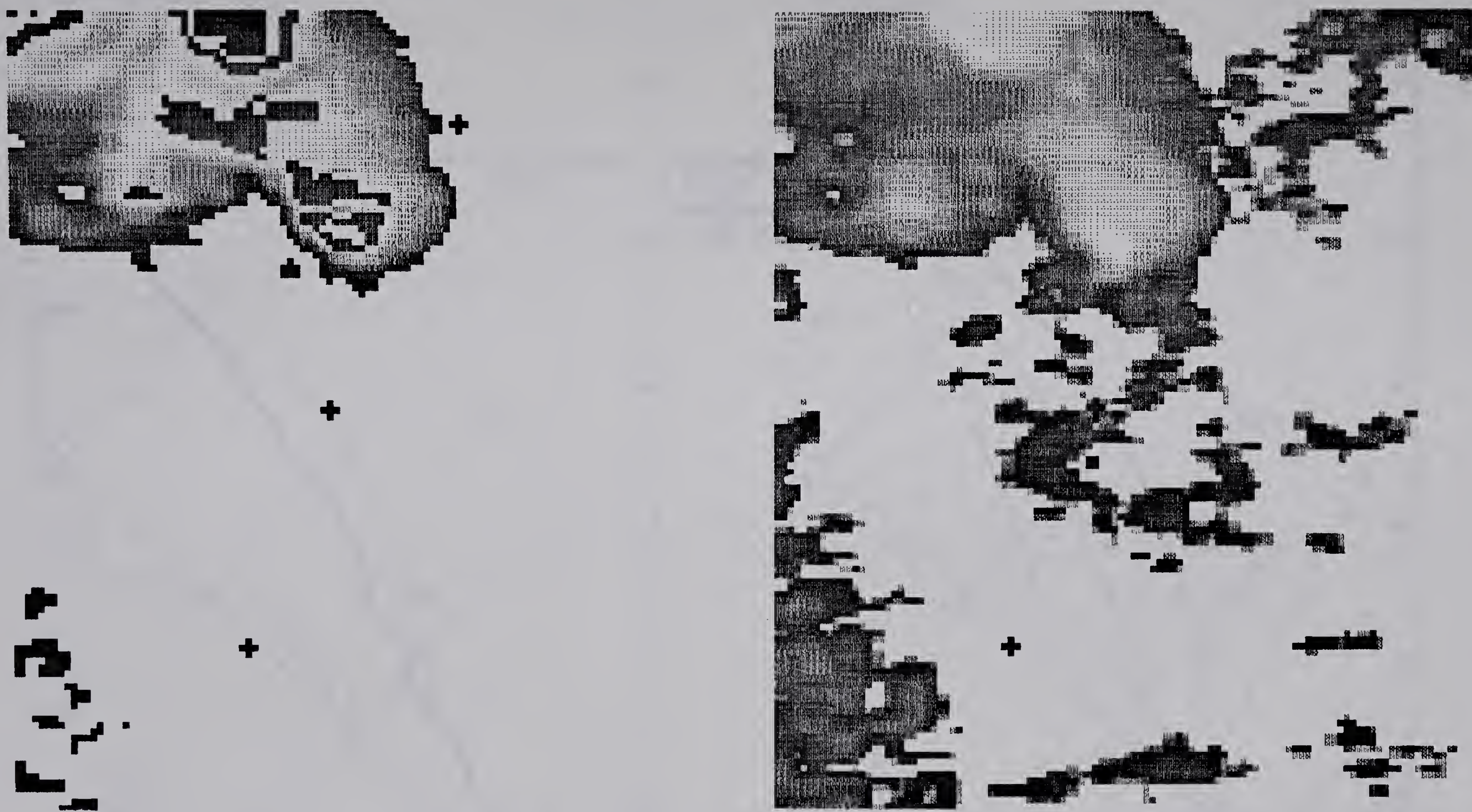


Figure 4.9 **500-mb and Surface maps July 7, 1979**

Figure 4.10 Contoured image from TIROS-N orbit 3772

a) Infrared, b) Visible.



a b

Figure 4.11 Grey level image from TIROS-N orbit 3772

a) Infrared, b) Visible.

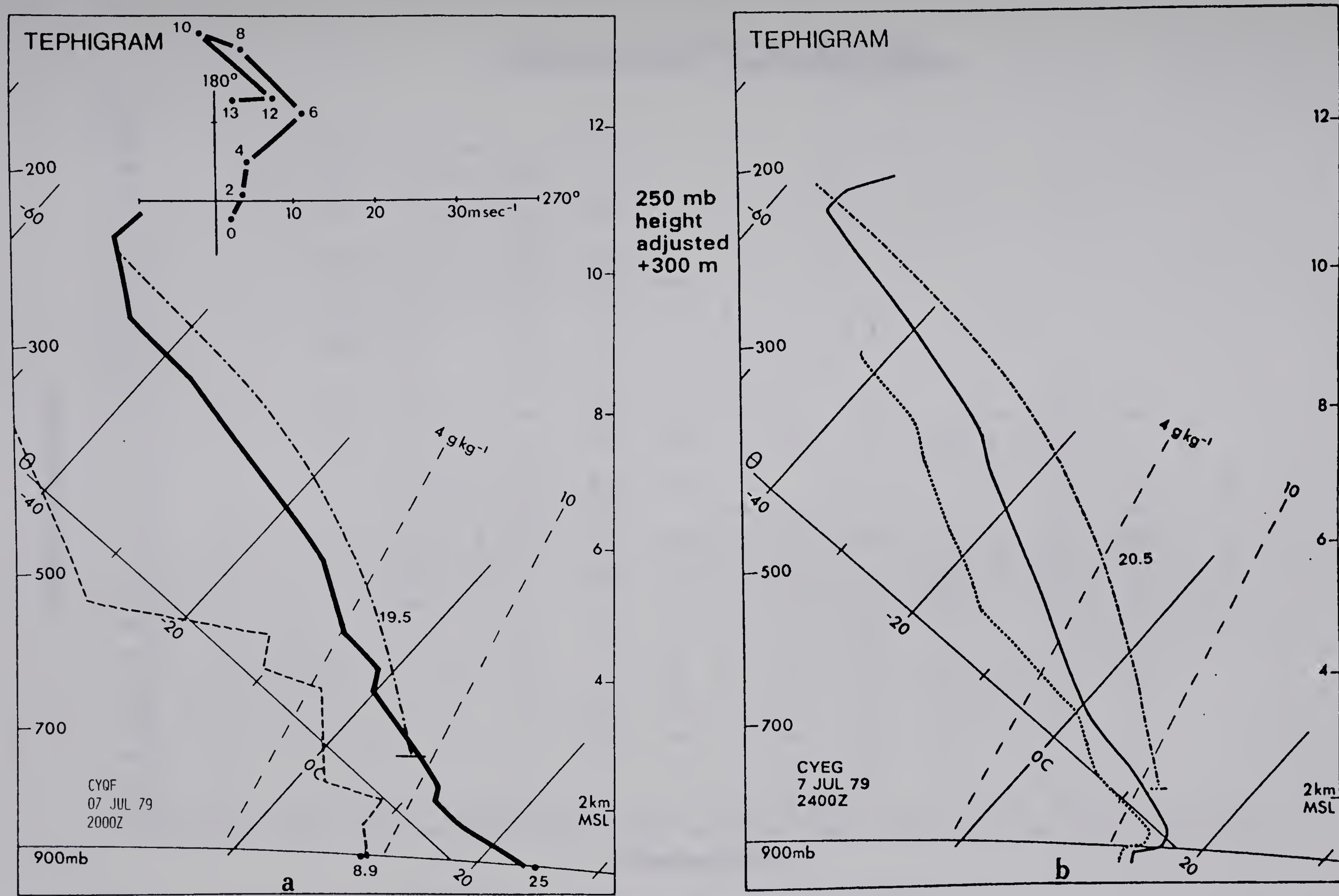


Figure 4.12 Tephigrams of radiosonde ascents, a) CYQF, b) CYEG.

VALUES GIVEN IN PERCENT OF TOTAL CLOUD COVER
18.2% CLOUD COVER OVER 41696. SQUARE KILOMETERS

Visible Reflectance \ Temperature (°C)	-65. to -60.	-60. to -55.	-55. to -50.	-50. to -45.	-45. to -40.	-40. to -35.	-35. to -30.	-30. to -25.	-25. to -20.	-20. to -15.	-15. to -10.	-10. to -5.	-5. to 0.	0. to 5.
175–170		0.4	0.3	0.1										
170–165	1.0	2.6	1.0	0.3	0.1									
165–160		1.8	4.1	0.7	0.1	0.2								
160–155		0.5	3.9	2.1	0.3	0.1								
155–150		0.6	2.2	2.0	0.7	0.2	0.2							
150–145		0.7	1.7	1.4	0.9	0.2	0.1	0.1		0.2		0.2		
145–140		0.9	0.6	1.4	0.5	0.3		0.2	0.1			0.1		
140–135		0.9	0.5	1.7	0.9	0.3	0.2	0.2					0.3	
135–130		0.4	1.3	1.3	0.4	0.3	0.2	0.1	0.2	0.2		0.2	0.1	0.1
130–125		0.2	1.3	1.0	0.7	0.8	0.3	0.2	0.2		0.1	0.2	0.5	
125–120			1.4	0.9	0.5	0.6	0.3	0.2				0.3	0.9	0.1
120–115			1.9	0.9	0.6	0.3		0.2	0.1				1.8	0.5
115–110			1.8	0.9	0.2	0.3	0.6	0.2	0.2	0.1		0.1	1.1	0.8
110–105			1.3	0.8		0.3	0.5	0.2	0.3		0.1	0.1	1.0	1.4
105–100			0.5	1.1		0.2	0.4	0.3	0.5	0.4	0.3		0.7	2.0
100–95			0.2	1.2	0.3	0.1	0.3	0.3	0.4	0.3			0.5	2.3
95–90				0.6	0.5		0.3	0.2	0.3	0.5	0.4	0.3	0.3	1.9
90–85					0.5	0.3	0.2	0.4	0.5	0.4	0.3	0.4	0.3	1.4
85–80						0.7	0.3	0.3	0.7	0.6	0.5	0.8	0.5	1.4
80–75							0.4	0.2	0.3	0.2	0.4	0.5	0.5	0.4
75–70								0.7	0.5	0.4	0.3	0.5	0.6	1.4

Table 4.3 Frequency table for orbit 3772.

4.6.3 Case Study #3 July 10,1979

At 2400Z on July 10, 1979, the 500-mb flow was from the southwest with a short-wave trough just to the southwest of the study area at 2400Z. The surface map for that evening indicated a light northwesterly wind (figure 4.13). The CDC was 4 and there were 234 hail reports with a median time of 2200Z.

Figures 4.14 and 4.15 are the contour and grey level maps from orbit 3814 which crossed the study area at 2145Z. From these figures it is evident that there were four or possibly five convective cells aligning themselves perpendicular to the 500-mb flow.

The tephigrams for CYQF (2000Z) and CYRM (2400Z) (figure 4.16) indicate cloud-tops at −49°C (10.3 km) and −46°C (10.2 km), (parcel method −64°C, 12.6 km), respectively. The radar-top estimate was 8.0−9.2 km (26−30,000 ft). The satellite estimate of cloud-top temperature was −50°C (10.4 km) as seen in figure 4.14a.

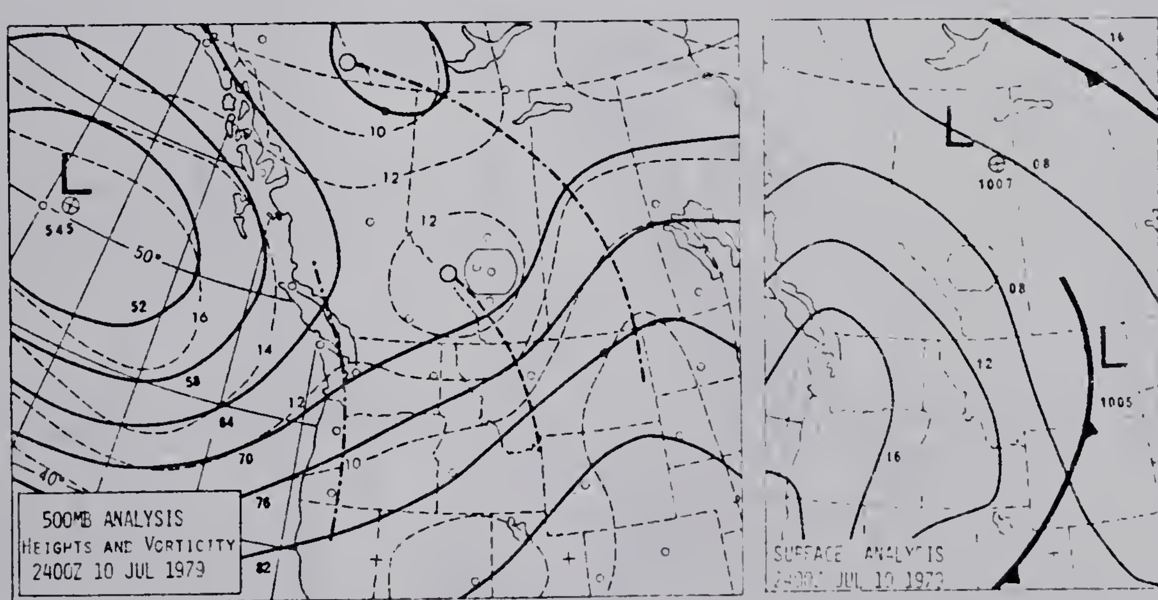
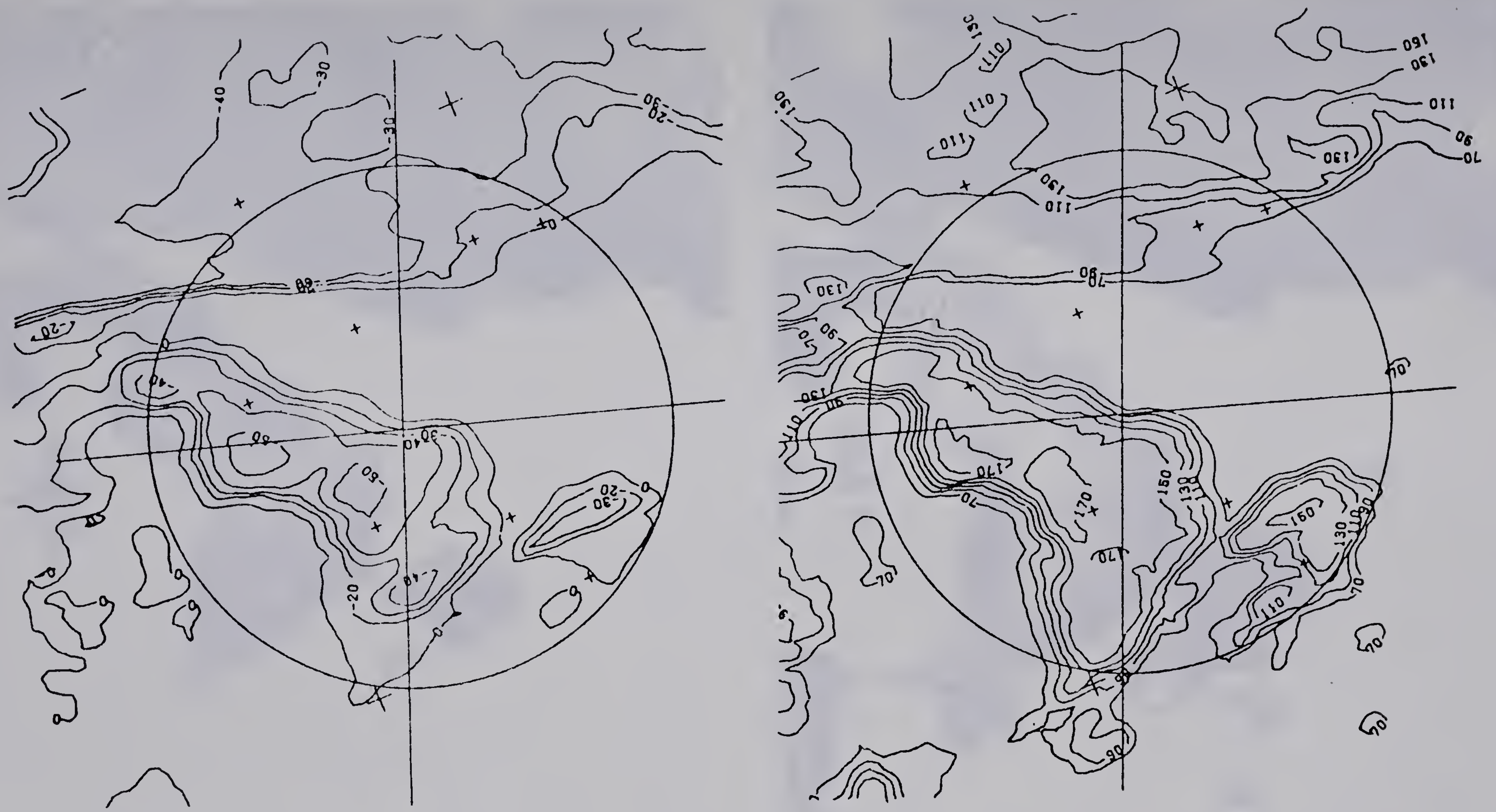


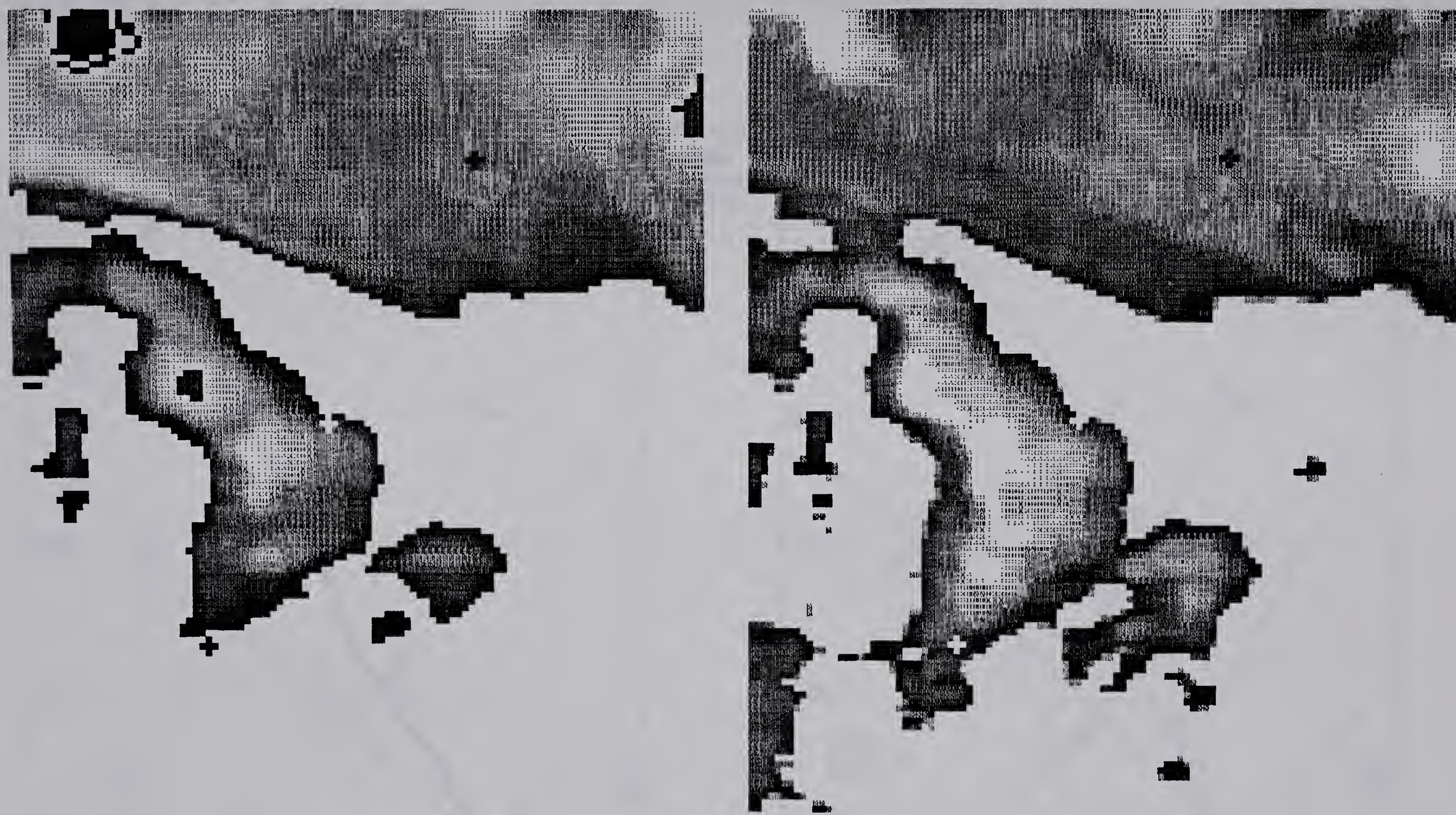
Figure 4.13 500-mb and Surface maps July 10, 1979



a b

Figure 4.14 Contoured image from TIROS-N orbit 3814

a) Infrared, b) Visible.



a b

Figure 4.15 Grey level image from TIROS-N orbit 3814

a) Infrared, b) Visible.

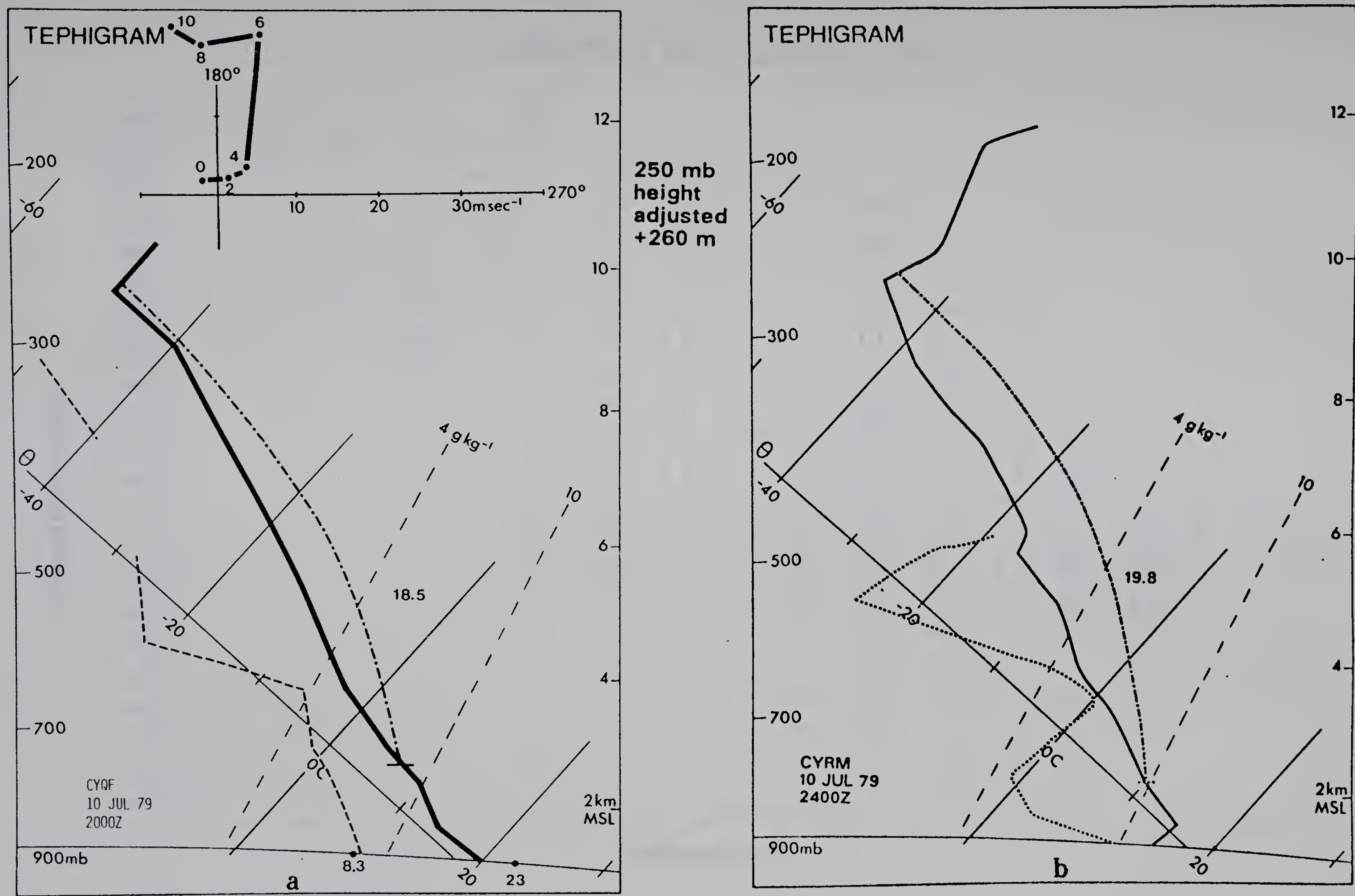


Figure 4.16 Tephigrams of radiosonde ascents, a) CYQF, b) CYRM.

VALUES GIVEN IN PERCENT OF TOTAL CLOUD COVER
45.8% CLOUD COVER OVER 46923. SQUARE KILOMETERS

Visible Reflectance \ Temperature (°C)	-65. – -60.	-60. – -55.	-55. – -50.	-50. – -45.	-45. – -40.	-40. – -35.	-35. – -30.	-30. – -25.	-25. – -20.	-20. – -15.	-15. – -10.	-10. – -5.	-5. – 0.	0. – 5.
180–175					0.2									
175–170	0.1	0.3	0.4	0.5	0.2	0.2	0.2	0.1						
170–165	0.1	0.4	0.6	0.6	0.3	0.3	0.2	0.2						
165–160			0.6	1.0	1.1	0.5	0.3			0.2				
160–155		0.1	0.4	1.0	1.0	0.8	0.3	0.1	0.1	0.3	0.3			
155–150			0.2	1.0	1.1	0.8	0.4	0.1	0.1	0.2	0.4			
150–145		0.1	0.2	0.9	1.3	1.2	0.7	0.5		0.1	0.6	0.2		
145–140			0.4	0.7	1.0	1.0	0.9	1.1	0.1	0.1	0.4	0.2		
140–135			0.2	1.1	1.5	1.2	1.5	1.6	0.4		0.3	0.4		
135–130				0.9	1.4	1.6	1.2	0.9	0.3	0.2	0.2	0.4		
130–125				1.6	1.3	1.9	1.3	0.6	0.5	0.2	0.3	0.5	0.2	
125–120				2.0	1.1	1.0	0.8	0.7	0.6	0.4	0.2	0.6	0.3	
120–115				1.2	1.7	0.7	0.9	0.4	0.5	0.3	0.3	0.5	0.3	
115–110				0.6	0.9	0.9	0.7	0.4	0.3	0.3	0.3	0.4	0.4	0.2
110–105				0.5	1.4	0.7	0.9	0.5	0.7	0.3	0.2	0.4	0.8	0.4
105–100				0.1	1.4	1.3	0.6	0.4	0.5	0.5	0.2	0.3	0.8	0.4
100–95					0.3	1.0	0.7	0.2	0.4	0.5	0.3	0.3	0.7	0.7
95–90							0.4	0.3	0.3	0.4	0.5	0.5	0.5	0.6
90–85								0.2	0.3	0.3	0.6	0.4	0.7	1.0
85–80									0.3	0.5	0.4	0.4	0.4	0.7
80–75										0.1	0.2	0.4	0.6	0.7
75–70											0.1	0.4	0.5	0.7

Table 4.4 Frequency table for orbit 3814.

4.6.4 Case Study #4 July 21,1979

The synoptic situation (figure 4.17) on July 21,1979 was characterized by a low-pressure system centered over the southern project area; the 500-mb flow was from the southwest with a short-wave trough over central British Columbia. The CDC was 5 (golf ball size), and there were 247 reports of hail with a median time of 2335Z. From figures 4.18 and 4.19 (the contour and grey level maps for orbit 3970 at 2314Z), it is evident that two cells with tops to −64°C existed over the study area. Since the 2000Z ascent at YQF (figure 4.20a) was not recorded over 250-mb, the extrapolated height of the tropopause from the 2400Z CYEG, CYYC, and CYRM soundings was determined to be at −52°C (11.9 km). The ascent from CYEG at 2400Z (figure 4.20b) indicated a cloud-top at −55°C (12.4 km), (parcel method −74°C, 14.6 km). On inspection of figure 4.20a one can see that there were large areas of cloud colder than −62°C (13.2 km). The radar for this case gave an estimate of 12.6−13.8 km (41−45,000 ft).

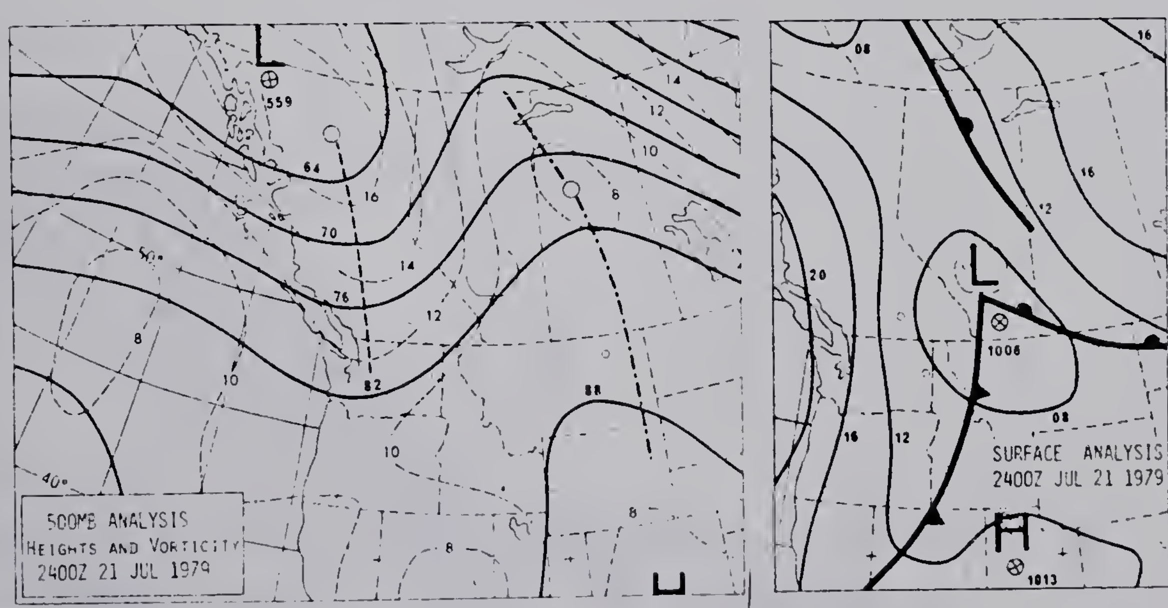


Figure 4.17 **500-mb and Surface maps July 21, 1979**

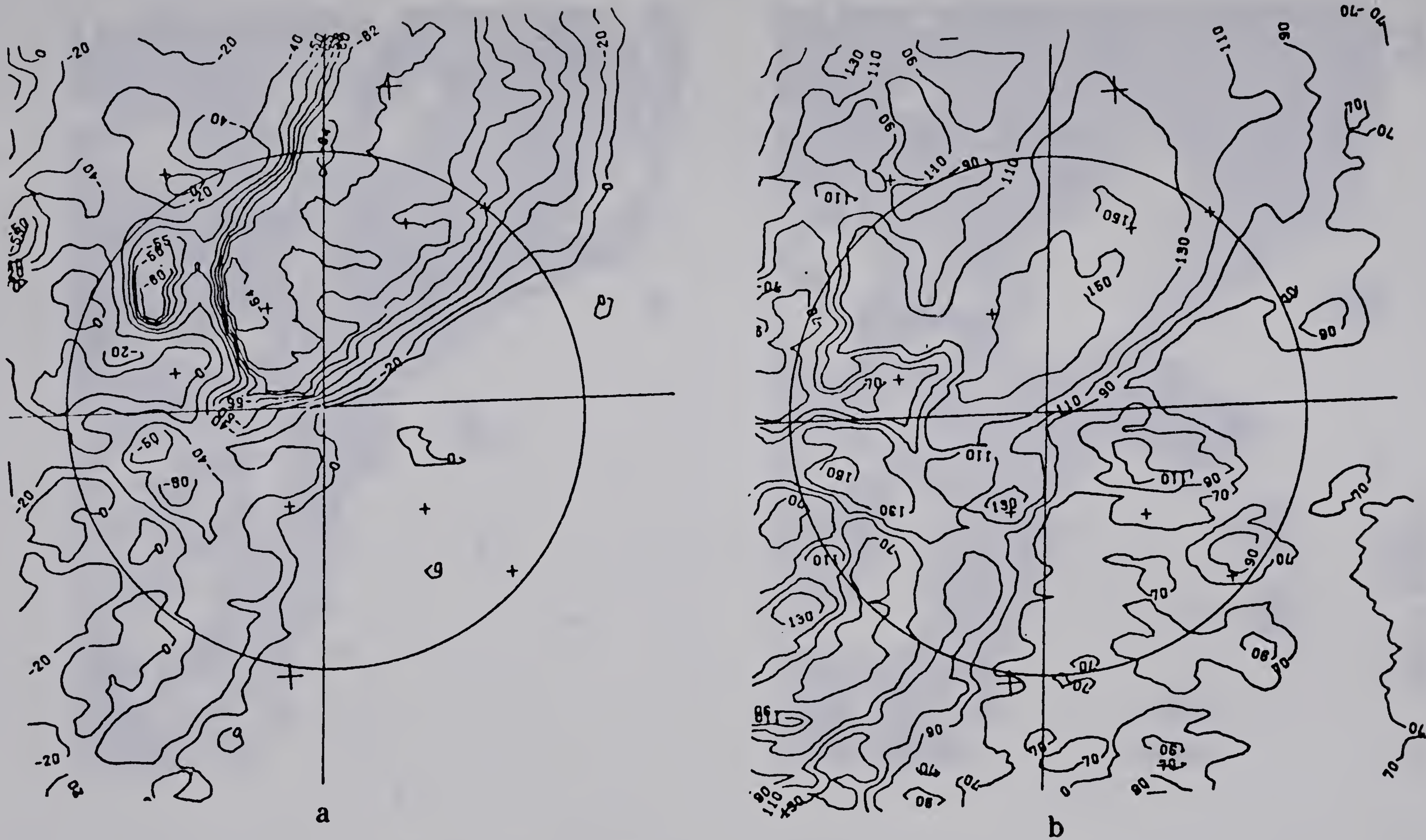
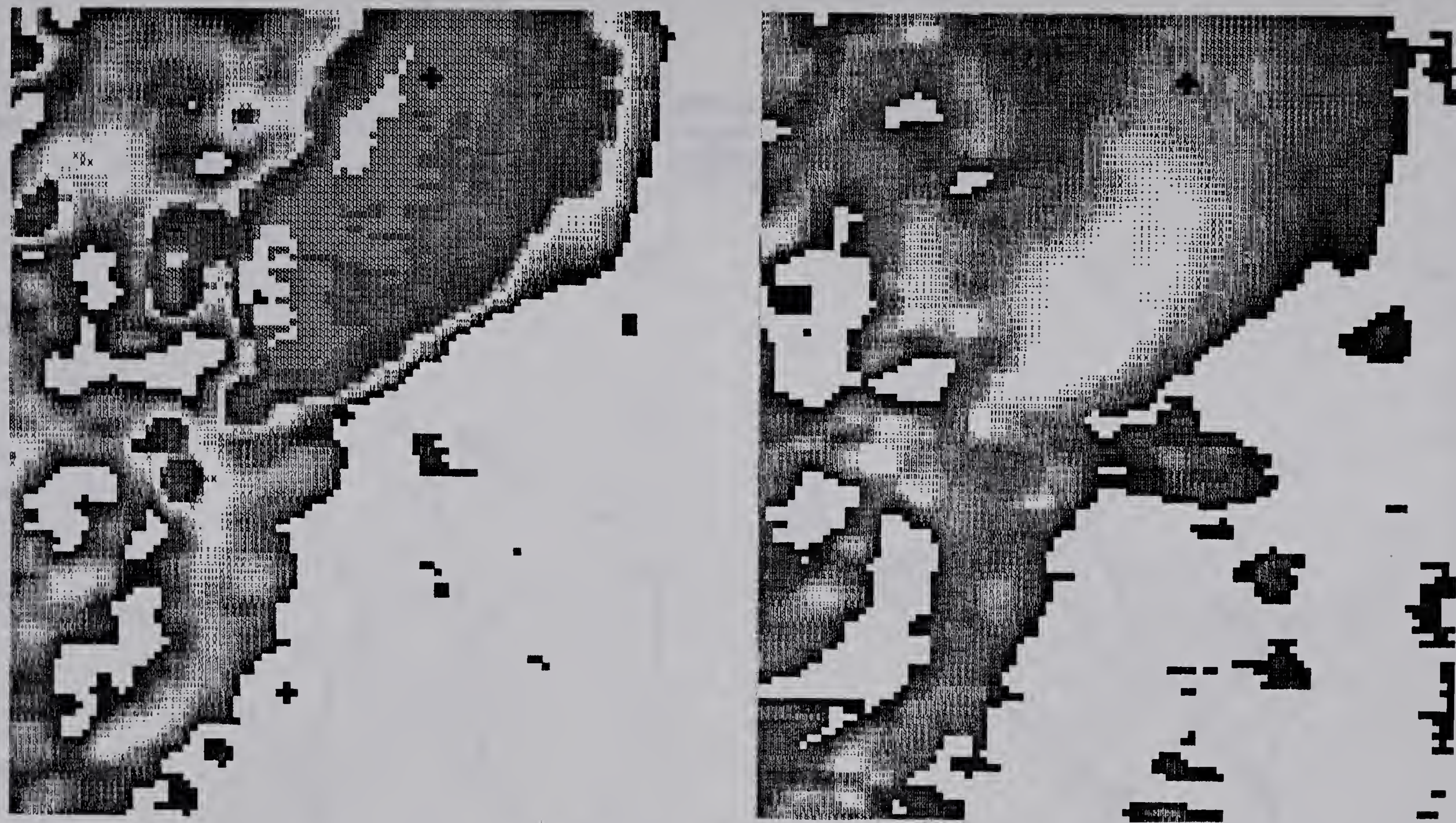


Figure 4.18 Contoured image from TIROS-N orbit 3970

a) Infrared, b) Visible.



a b

Figure 4.19 Grey level image from TIROS-N orbit 3970

a) Infrared, b) Visible.

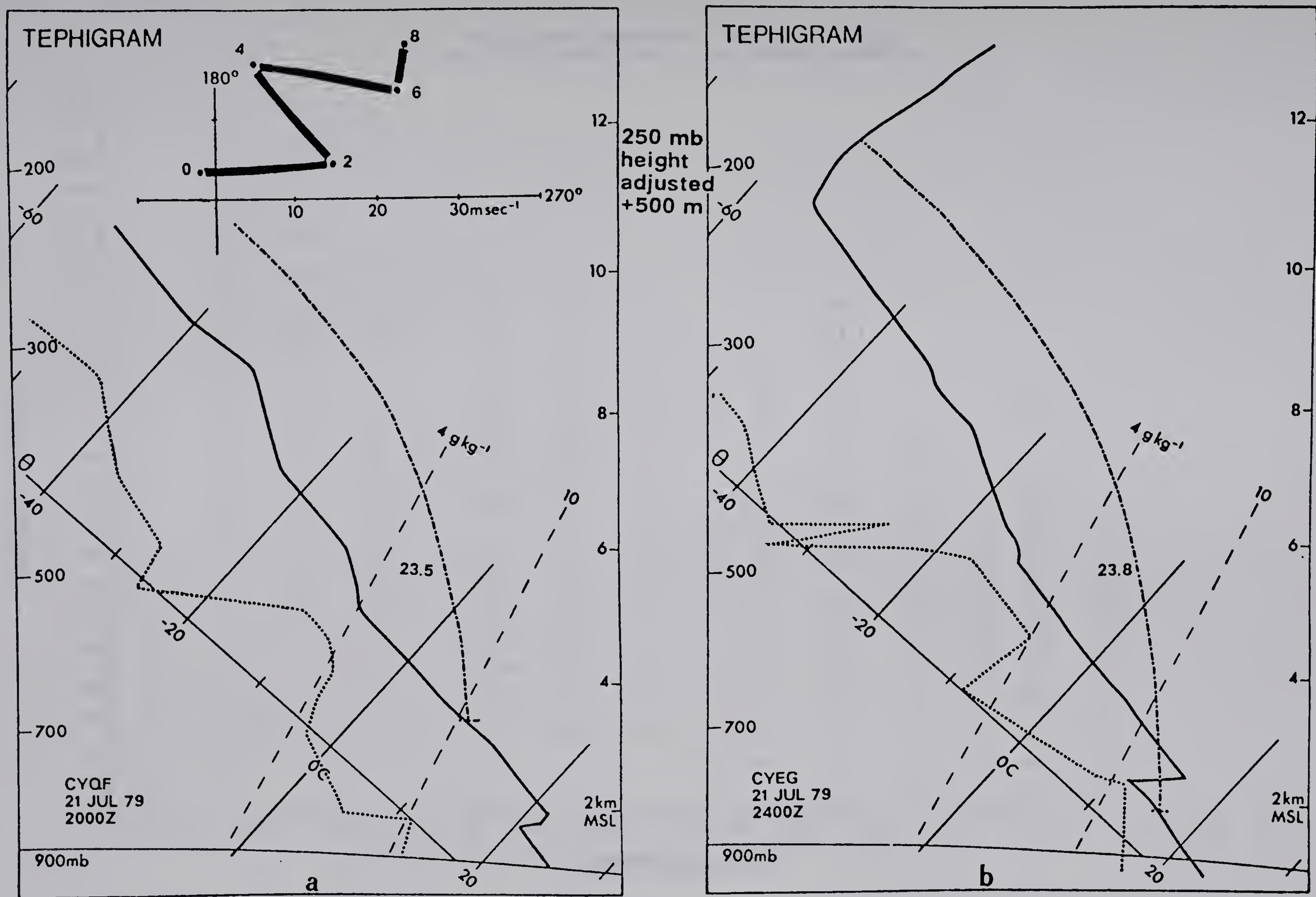


Figure 4.20 Tephigrams of radiosonde ascents, a) CYQF, b) CYEG.

VALUES GIVEN IN PERCENT OF TOTAL CLOUD COVER
54.0% CLOUD COVER OVER 32215. SQUARE KILOMETERS

Visible Reflectance \ Temperature (°C)	-65.	-60.	-55.	-50.	-45.	-40.	-35.	-30.	-25.	-20.	-15.	-10.	-5.	0.
165	0.1													
160	0.2													
155	0.7	0.4												
150	3.0	0.6	0.1	0.1					0.1					
145	3.3	0.8	0.3	0.1	0.1	0.2	0.1			0.1				
140	1.8	1.0	0.5	0.2	0.1	0.2	0.2	0.1	0.1	0.1				
135	2.2	0.9	0.5	0.3	0.2	0.3	0.2	0.2	0.2	0.3				
130	1.7	0.6	0.5	0.6	0.3	0.3	0.4	0.4	0.4	0.2			0.1	
125	1.7	0.5	0.3	0.4	0.4	0.4	0.5	0.3	0.5	0.4	0.2			
120	2.4	0.5	0.3	0.4	0.5	0.6	0.5	0.7	0.6	0.3	0.3	0.1		
115	1.3	0.8	0.3	0.2	0.5	0.6	0.8	0.7	0.7	0.5	0.2		0.3	0.1
110	0.6	1.2	0.2	0.3	0.4	0.4	0.8	1.0	0.8	0.6	0.3	0.2	0.2	0.3
105		1.4	0.7	0.3	0.5	0.5	1.0	0.8	0.8	0.7	0.4	0.3	0.1	0.2
100		0.7	1.3	0.4	0.4	0.4	0.7	0.5	0.7	0.6	0.6	0.3	0.3	0.3
95			0.8	0.8	0.4	0.4	0.7	0.4	0.5	0.5	0.9	0.6	0.3	0.4
90			0.2	0.6	0.9	0.7	0.6	0.6	0.7	0.6	0.6	0.6	0.4	0.4
85					0.3	1.0	0.7	0.9	0.9	0.6	0.7	0.7	0.8	0.8
80						0.1	0.5	1.0	1.1	0.9	0.7	0.6	0.7	0.8
75								0.2	0.3	0.6	0.9	0.9	0.7	0.7
70										0.2	0.3	0.7	1.2	1.3

Table 4.5 Frequency table for orbit 3970.

4.6.5 Case Study #5 July 16, 1980

The synoptic situation the afternoon of July 16, 1980 was dominated by a 500-mb low-pressure system centered over Slave Lake, Alberta (Figure 4.21). At this time a short wave trough was oriented NE-SW just west of the project area. A surface low was located in northeastern Saskatchewan, surface winds over the project area at 2400Z were light and from the north. The CDC was 5, there were 410 cases of hail reported with a median time of 2300Z.

From the contour and grey level maps (Figures 4.22, and 4.23 respectively) one can see that the main storm feature at 2225Z was one well organized storm over Rocky Mountain House. The contour map yields an estimate of −53°C (10.2 km) for the storm's top. The CYRM radiosonde ascent (figure 4.24b) yielded an estimate of −47°C (9.7 km), (parcel method −66°C, 11.7km). The concurrent radar estimate for this storm was 9.3-11.9 km (35-41000 ft).

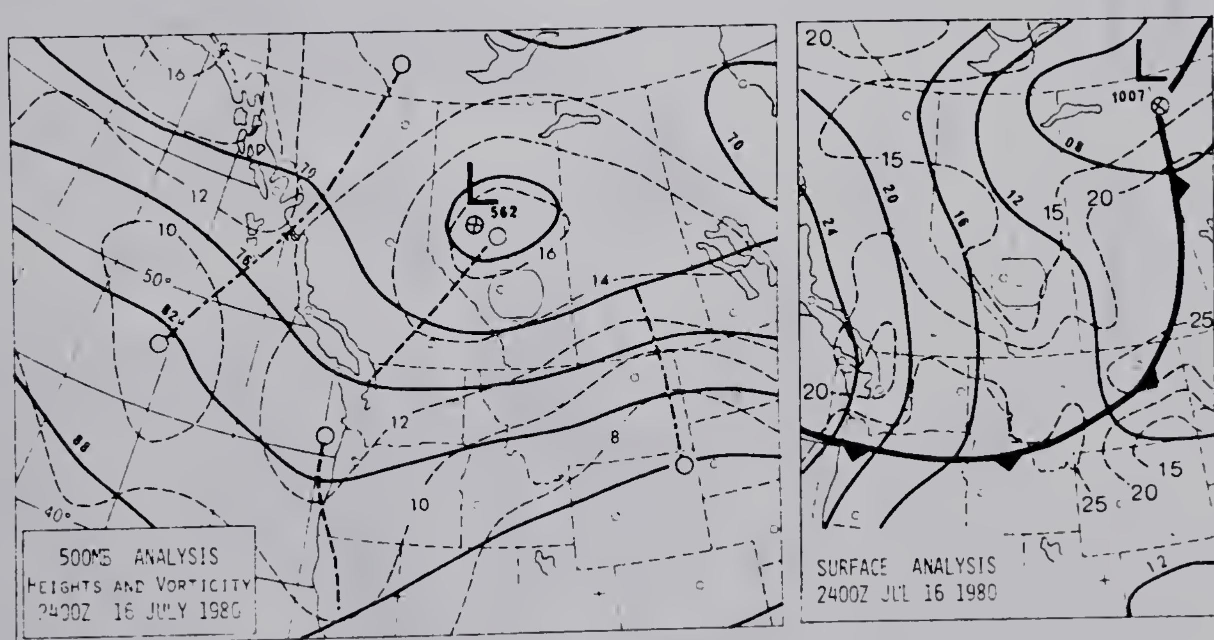


Figure 4.21 **500-mb and Surface maps July 16, 1980**

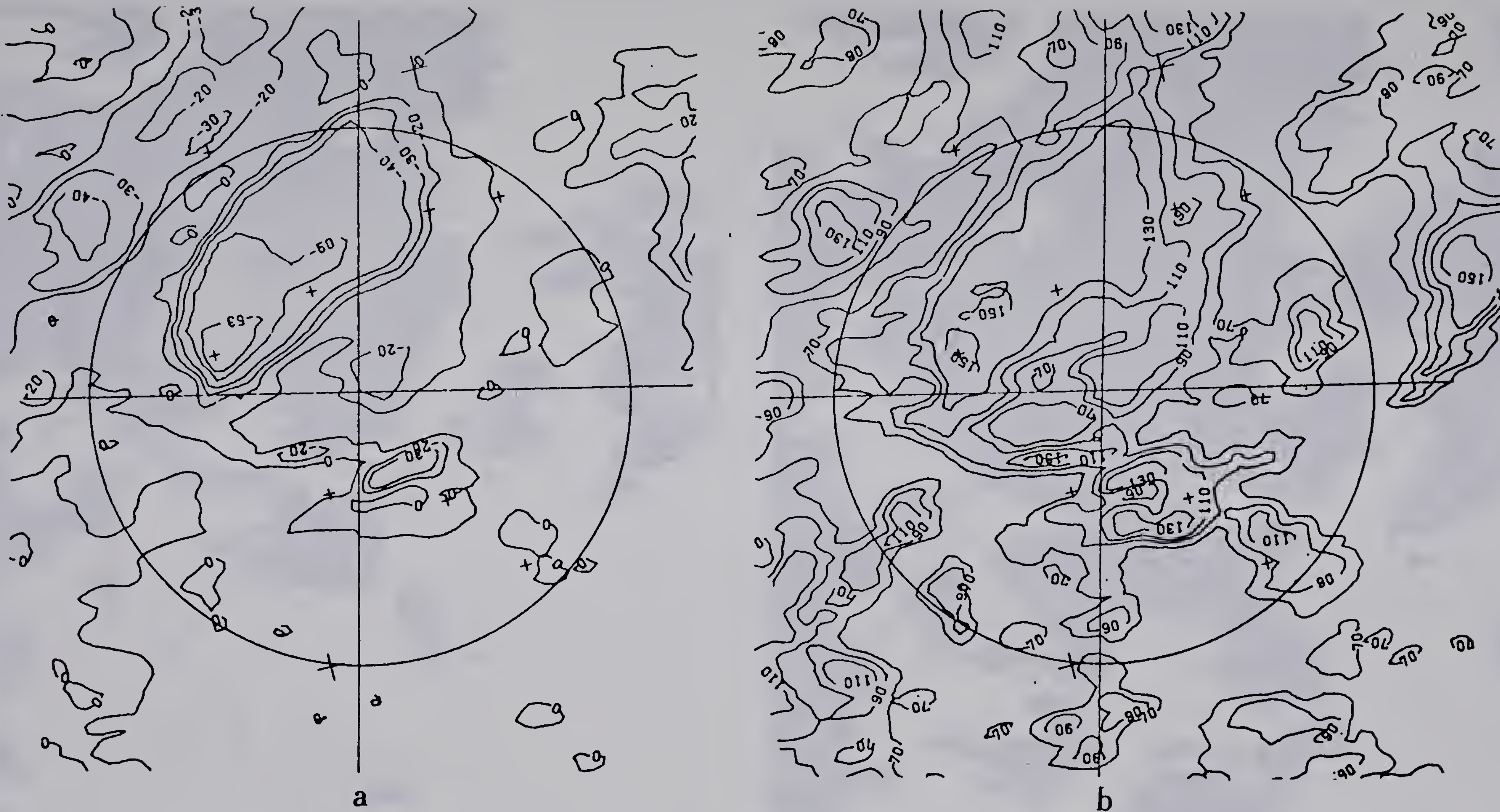
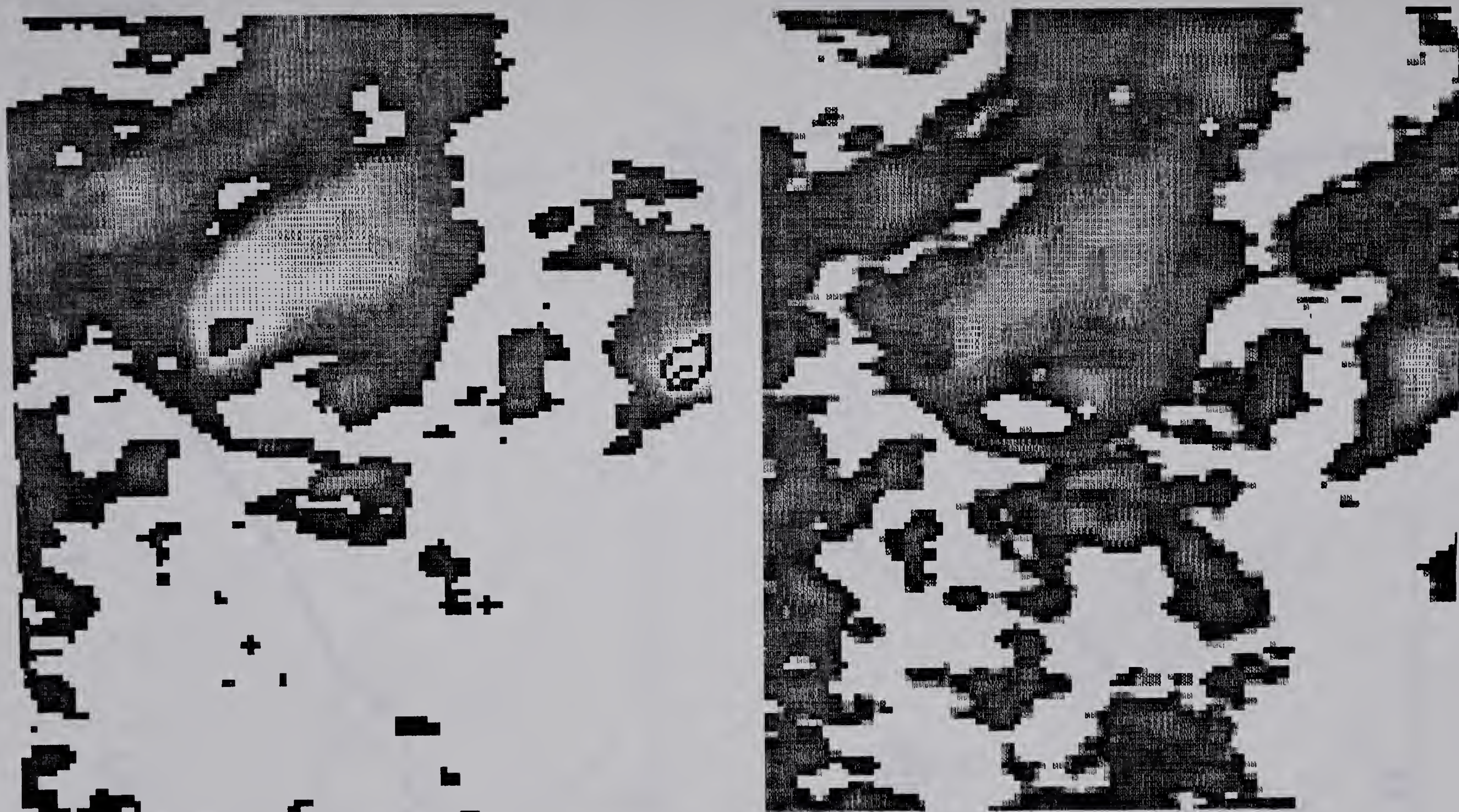


Figure 4.22 Contoured image from TIROS-N orbit 9063

a) Infrared, b) Visible.



a b

Figure 4.23 Grey level image from TIROS-N orbit 9063
a) Infrared, b) Visible.

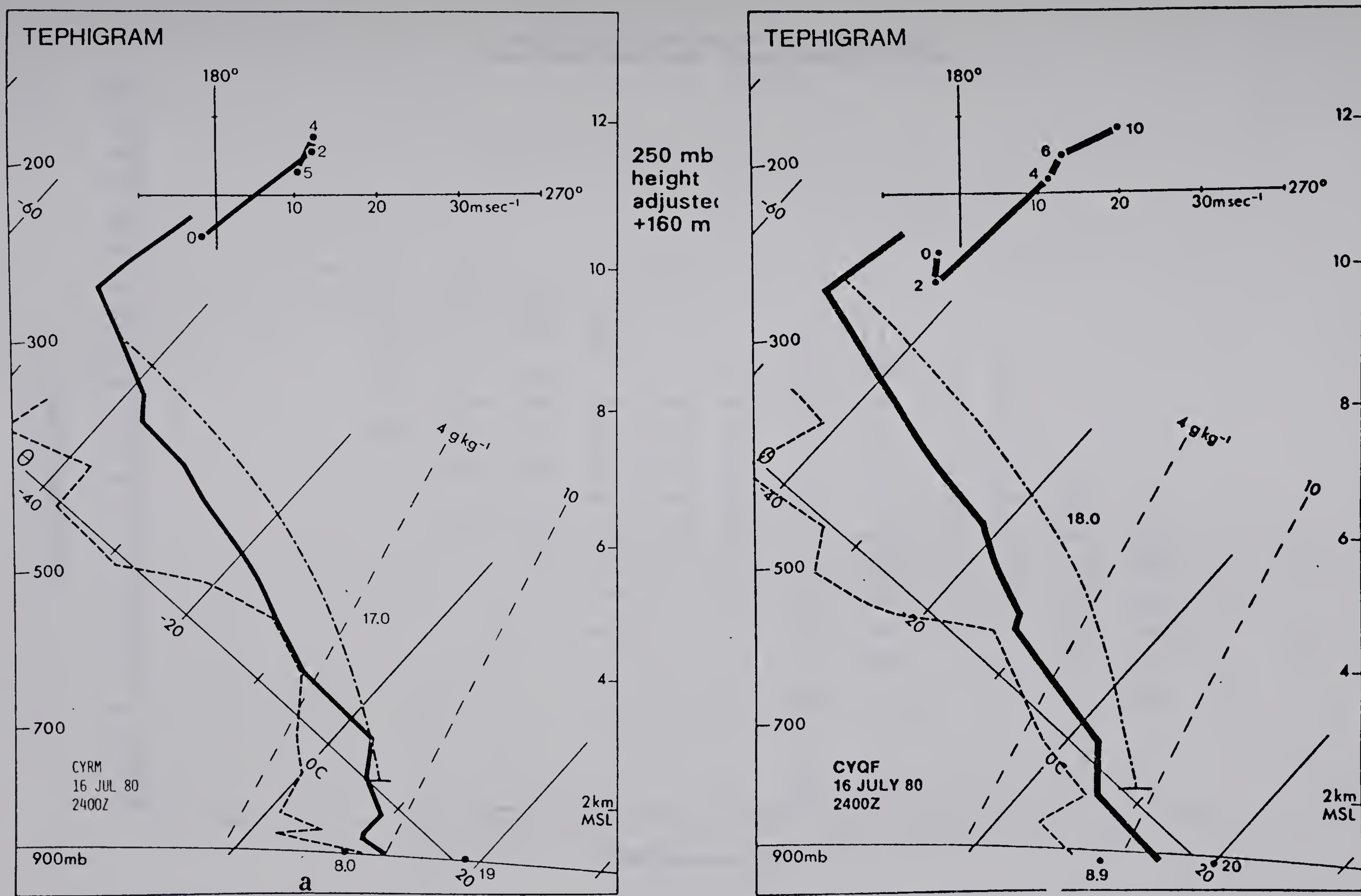


Figure 4.24 Tephigrams of radiosonde ascents, a) CYQF, b) CYRM.

VALUES GIVEN IN PERCENT OF TOTAL CLOUD COVER
36.2% CLOUD COVER OVER 42369. SQUARE KILOMETERS

Visible Reflectance	-60. to -55.	-55. to -50.	-50. to -45.	-45. to -40.	-40. to -35.	-35. to -30.	-30. to -25.	-25. to -20.	-20. to -15.	-15. to -10.	-10. to -5.	-5. to 0.	0. to 5.
180													
175													
170													
165													
160													
155	0.1	0.2	0.1										
150	0.2	0.7	0.1										
145	0.4	1.9	0.8	0.4									
140		1.3	1.8	0.4	0.2			0.1					
135		0.3	1.1	0.7				0.3	0.2	0.1	0.2		
130		0.1	0.5	0.6	0.4	0.2	0.1	0.3	0.3	0.5	0.2		
125		0.1	0.4	0.4	0.4	0.3	0.1	0.4	0.5	0.7	0.4		
120			0.3	0.3	0.5	0.3	0.2	0.3	0.6	0.8	0.5	0.1	
115					0.4	0.5	0.4	0.5	0.5	1.0	0.8	0.3	0.1
110			0.2	0.3	0.3	0.5	0.3	0.4	0.7	0.9	1.2	0.6	0.1
105				0.1	0.2	0.6	0.8	0.7	0.8	1.4	1.6	1.2	0.4
100					0.5	0.4	0.6	0.8	0.8	1.5	1.9	1.4	1.0
95					0.3	0.6	0.7	1.0	0.9	1.5	1.7	1.6	1.5
90					0.4	0.8	0.8	0.8	0.9	1.1	2.2	2.1	1.4
85					0.1	0.8	1.1	0.8	0.9	0.9	1.7	2.0	1.9
80					0.2	0.6	1.7	1.0	0.7	0.8	1.8	2.3	1.8
75						0.4	1.3	1.3	1.0	1.0	1.3	2.5	2.7
70							0.5	1.0	1.2	1.2	1.4	1.6	2.7

Temperature axis: -70. -65. -60. -55. -50. -45. -40. -35. -30. -25. -20. -15. -10. -5. 0. 5. 10.

Temperature (°C)

Table 4.6 Frequency table for orbit 9063.

5. Rain Estimation from Satellite Data

5.1 Introduction

The estimation of rainfall over extensive areas is important in several ways. For example, such estimates are needed for improved calculations of both the water balance over oceans and continents, and the heat balance of the atmosphere.

Several attempts have been made to estimate rainfall from satellite data. A comprehensive review of satellite rainfall estimation methods is given by Martin and Scherer (1973). It has been well established that the area of convective rain (as determined from radar) is closely related to precipitation areas. Gruber (1973) indicated that the area of the radar echo return is well defined on satellite imagery by cold (i.e., high) clouds. Lethbridge (1967) compared TIROS-IV visible and infrared radiation for several localities with the occurrence of precipitation three to twelve hours following the satellite pass. It was found that the probability of rain for a twelve-hour period is higher than that for a three-hour period. Woodley and Sancho (1971) in their paper comparing satellite and rainfall data state: "The correspondence between echo and brightness area is best when the cloud system is young and vigorous, and worst when it is old and decaying." This is most likely due to the fact that mature clouds are colder and brighter than young ones because of their cirrus canopies.

Research suggests a generally positive relationship between rainfall and bright, cold clouds. However, it is also apparent that the use of time-integrated data of satellite imagery will produce a better correlation with the radar-determined rainfall areas than can be produced by instantaneous values.

5.2 Rain Area Determination

Although a majority of the research involving the estimation of rain intensity from satellite data is inconclusive, several tests were performed in order to determine what combinations of visible and infrared data correspond best with concurrent radar PPI's.

The first of these tests was run using cut-off values from previous research trying to determine rain areas from satellite data. Assuming that the visible digital counts

for GOES and TIROS–N data represent the same visible reflectance, values found by Griffiths (1978) were used to define the cut–off between the rain – no rain areas. The no rain area is defined by pixels with an infrared temperature higher than −20°C and a visible digital count of less than 80. According to Griffiths (1978), 88% of the clouds with a temperature of less than −20°C and digital counts greater than 80 will have radar echos. Thus, the rain area is assumed to be described by all pixels with temperatures lower than −20°C and digital counts greater than 80. Heavy rain areas were chosen to be all those pixels having a digital count of 120 or greater and a temperature of −50°C or less. Cheng (1977) found, 84.3% of the total rain area and 92.2% of the total rain amount will be within this area when using TIROS–N data.

The results given by the above values showed poor correlation with the radar PPI's, generally yielding larger "rain areas" than those inferred from the concurrent PPI's. The reason for this discrepancy may be due to a variety of factors. The first explanation that comes to mind is the possibility that the assumptions made regarding the correspondence between the GOES and TIROS–N visible data are poor.

A second reason might be the difference in geographical location. Both Griffiths and Cheng used data from Florida thunderstorms (27° N), while the data in this study involved storms over central Alberta (51° N). Although both studies were conducted in early summer within a few hours of local noon, the sun elevation angle varies by at least 26°. In all of these studies overhead lighting is assumed in order to simplify the sun elevation angle problem in the calibration of visible data. This overhead lighting assumption may not be valid over central Alberta where the sun elevation angle is 60° in early July.

The most likely reason for the apparent difference in results is the altitude difference between central Alberta (2200'–3500' msl) and the area around Miami, Florida (0'–20' msl). Miami's close proximity to the ocean and lower elevation, and Alberta's location on the leeward side of a mountain barrier indicate a larger amount of water vapour is available over Miami than is available over central Alberta. It is due to these differences that clouds at low elevations produce precipitation at lower heights and higher temperatures than clouds over higher elevations (Battan and Braham, 1956).

Two methods, chosen for their consistency and operational simplicity, were tested in order to determine the cut-off values for the rain areas. Program RAIN (Appendix C.9) was run with experimental cut-off values, and the data were contoured on a map in order to compare the resultant "rain area" with it's corresponding low-level PPI.

The first cut-off determination method involved contouring the brightest and coldest 5% of the cloud as the "heavy rain area", and the top 10% as the remaining "rain area". The percentages were determined from the frequency tables for each pass (Tables 4.2-4.5). This attempt yielded varied results for all cases tested. These results were thought to be influenced by the possibility of "sun glint" (ie. low sun elevation angle) skewing the visible digital counts in some cases. This skewing would only have to be very slight in order to make a significant difference in the reflectance of the top 10% of the cloud.

The second cut-off determination method involved using the same cut-off values for all satellite passes. After several attempts it was found that cut-off's of

−35°C, 134	"Rain area"
−50°C, 145	"Heavy rain area"

best approximated the PPI's.

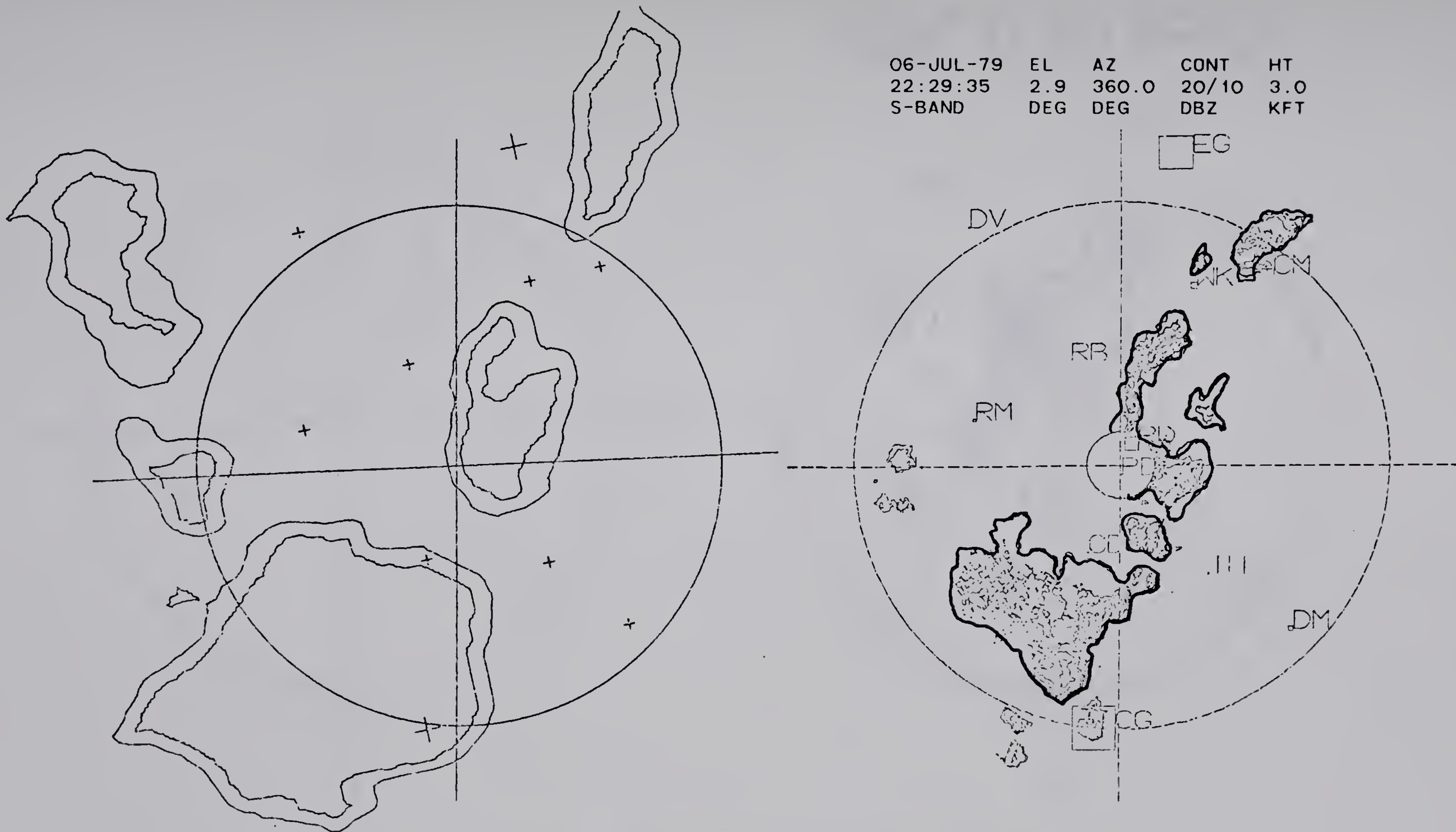
It appears that the over-estimate of rain areas by Griffith's values is due more to the difference in the visible reflectance cut-off than to a difference in temperature cut-off. This may be due to the assumption made about GOES and TIROS-N visible data, and may support the argument that the sun elevation angle is in fact crucial in this type of data analysis. It is interesting to note that the differences in the cut-off values found by Cheng and those found in these tests may be explained solely by the difference in the geographical location.

Two of the problems associated with the "across the board" cut-off method are: 1) if the values are chosen too high the method will eliminate some information in a few of the passes; 2) if they are chosen too low, unusually large "rain areas" will result. The values obtained in these tests were a compromise of these two conditions while considering four separate data sets.

Figures 5.1, 5.2, and 5.3 are the plots of both "rain area" and PPI's. Although the estimated rain area seems to overestimate the low-level PPI's area, the basic shape and location of the rain areas is close to that of the PPI's.

The PPI's in Figures 5.1 and 5.2 are marked with a heavy black line representing the spatial integration of the 1^0 to 4^0 elevation angle positions of the 20 DBZ contour. This combination seems to give the best agreement with the satellite-derived "rain areas".

It must be stressed that these cut-off values are dependent on the stage of development of the thunderstorm, and would be of little use in non-convective rain estimation. This conclusion was also reached by Lovejoy and Austin (1979), who stated: "For widespread rain (stratus) days and convective rain days for Montreal, the optimum (rain no-rain) boundry is significantly different."



a b

Figure 5.1 July 6, 1979 2230Z a) Satellite rain area estimation

b) Radar PPI.

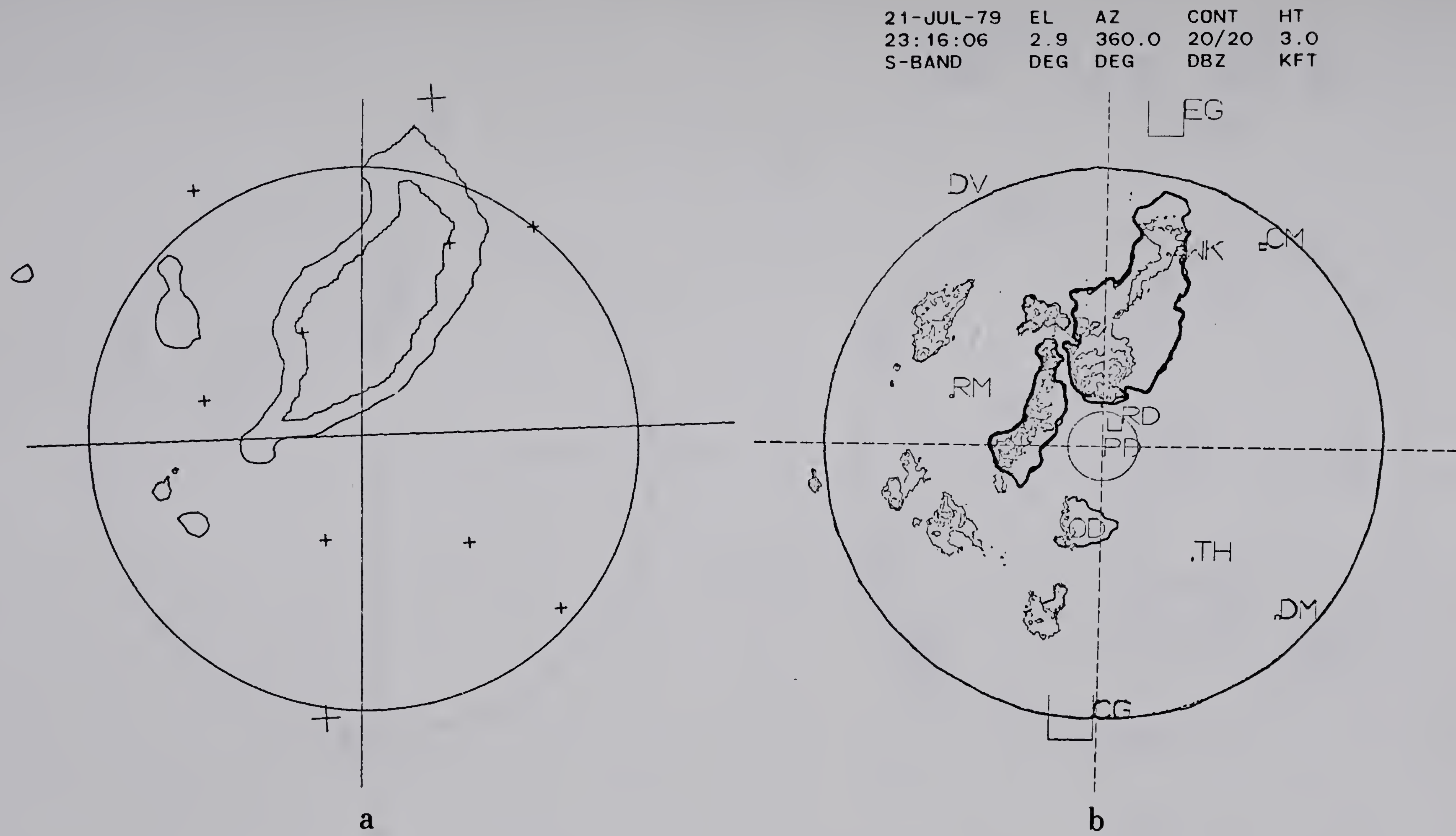


Figure 5.2 July 21, 1979 2315Z a) Sattelite rain area estimation

b) Radar PPI.

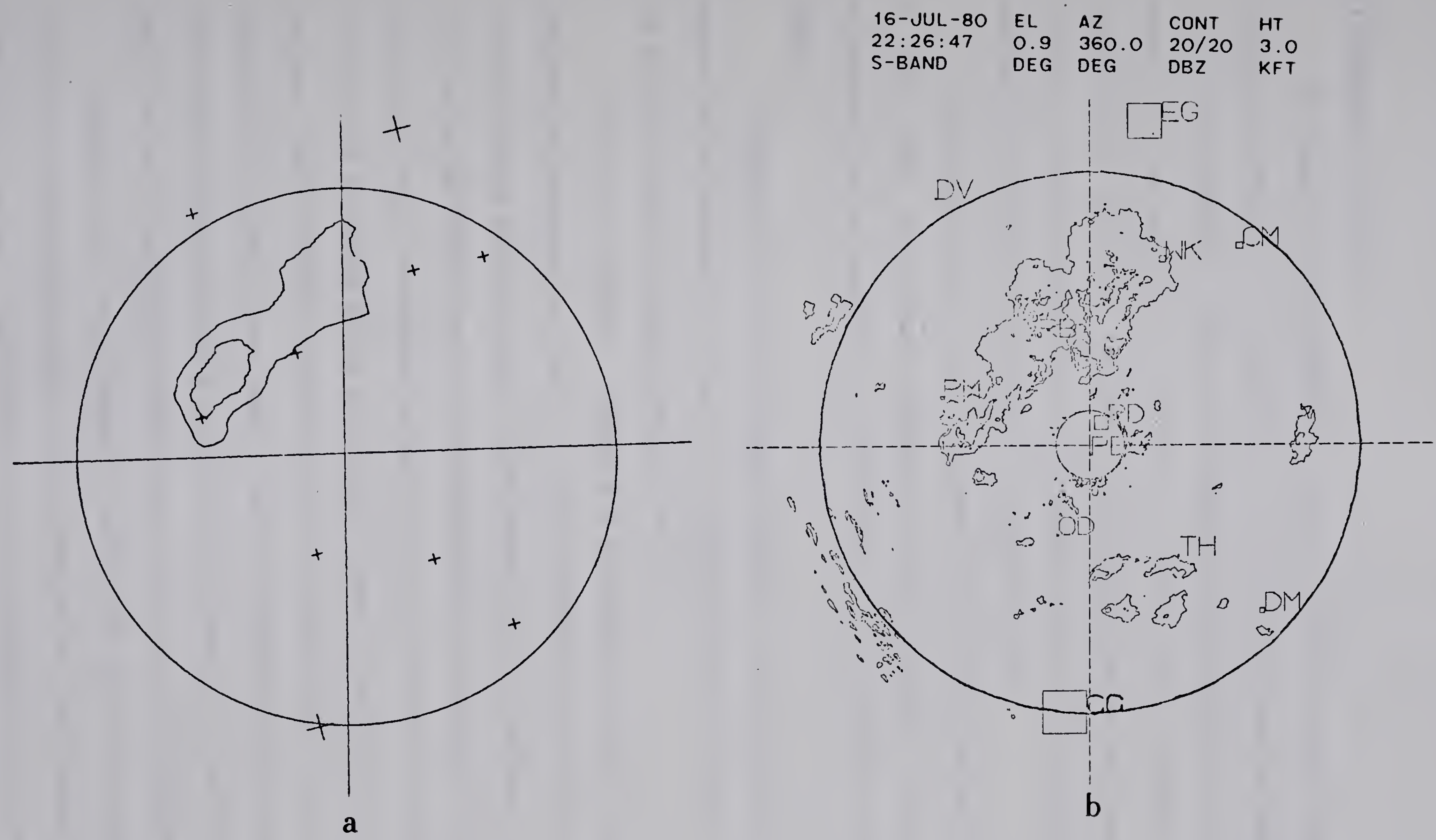


Figure 5.3 July 16, 1980 2226Z a) Satellite rain area estimation b) Radar PPI.

6. Summary and Conclusions

6.1 Summary of Results

The results found in Chapter 4 reveal that TIROS–N satellite data may yield the most accurate and economical estimation of cloud–top temperature available today.

The resolution of TIROS–N APT data (4 km^2) is sufficient for use in the study of mesoscale cloud patterns, and therefore it can be used as a tool in the study of thunderstorms. This 4 km^2 resolution is fine enough to detect the "convective bulge" due to local tropopause modification by penetrating turrets, yet it is unable to detect these individual turrets as they are are usually no larger than 2 km^2.

The temperatures derived in the manner discussed in Chapter 2 are calculated to be within $\pm 3^0$C of the true temperature of the radiating surface. This error in temperature can be translated to a maximum error of approximately 450 m in cloud top height.

In comparing the cloud–top height estimates from all case studies (Table 6.1), it is evident that all estimates are close to one another relative to the error limits of each of the individual cloud–top height estimation methods.

The results in Table 6.1 indicate that the satellite estimates were close to all the conventional estimates for cloud top height. Generally, the cloud–top height associated with the satellite data was slightly underestimated by the tephigram method when not using the parcel method, and highly overestimated by an average of 1.5 km when using the parcel method. The satellite estimate was at the low end of the radar estimate range in Case #1, in the middle of the radar estimate range in Cases #2 and #4, and higher than the upper radar estimate in Cases #3 and #5. Consideration of the possible errors and assumptions involved in determining cloud–top height by conventional methods implies that satellite data may provide a more accurate estimate of cloud–top temperatures and height than any other method available, short of direct aircraft measurements.

Besides being more accurate, satellite data are more representative of the meso–scale and synoptic–scale conditions than the few point measurements one obtains from radiosonde data. The satellite data are area–averaged, which eliminates any chance for an unrepresentative point estimate, as can be the case for a radiosonde sounding.

Table 6.1 Cloud top height estimates (km)

Case study	Satellite	Tephigram	Tephigram parcel method	Radar
Case #1	12.6	11.7-12.2	13.4	12.6-13.8
Case #2	11.5	11.1-11.5	13.3	11.1-12.3
Case #3	10.5	10.3-10.2	12.6	8.0-9.2
Case #4	13.2	11.9-12.4	14.6	12.6-13.8
Case #5	12.0	9.3-9.8	11.7	9.5-10.7

The fact that the satellite infrared data originate from the radiating surface make satellite cloud-top height estimates more accurate than a radar estimate, as radar cannot detect the top of the cloud, except in special circumstances, (eg. airborne, very short wave-length radar).

The rain area determination method discussed in Chapter 5 proved to yield a rain area estimation close the estimation from the low-level PPI in each case studied. Generally, the rain area as determined from the satellite data overestimated the rain area, which was assumed to be equivalent to the area enclosed by the 20 DBZ contour on a low-level PPI. These tests agree well with former work in this area, in that it was found that a short (5 min) time-integrated PPI yields the best correspondence with the satellite-derived rain area.

6.2 Applications

The potential applications of these satellite data are as wide-spread as the satellite's areal coverage. Accurate cloud-top temperatures are valuable to the cloud physicist for evaluation of cloud physics models, and to help assess the effectiveness of cloud seeding both of thunderstorms for hail supression, and of winter orographic clouds for snow pack augmentation.

These data can also be used for "truthing" other methods of cloud-top temperature measurement, such as cloud seeding or research aircraft. The large areal coverage of satellite data makes it possible to develop cloud climatologies over specific regions. Cloud cover and cloud size distributions of cloud greater than 4 km^2 may be numerically calculated over a given area far more accurately and economically than by any other method available. Infrared data alone can yield grid-point surface temperature data in data-sparse regions for input into heat budget and climate models. The mapping of natural disasters such as forest fires to assess damage is also possible from these data.

The rain area determination method derived in this study can be used to map rain areas over regions where no rain gauge or radar data is available. This routine is also of value in deriving cloud climatologies of precipitating clouds.

6.3 Recommendations for Future Study

The need for further work in this area is evident. More accurate methods for "ground truthing" and temperature retrieval would be a definite asset to the use and implementation of satellite data in cloud physics research.

The effects of long-wave atmospheric attenuation has only been briefly mentioned in this work. The application of a radiation transfer model, based on current atmospheric conditions, would yield a far more accurate satellite product.

The "ground truthing" of satellite data could be greatly improved over the rough estimates of cloud-top height used in this study by the implementation of a thunderstorm cloud model which considers the effects of viscous drag, entrainment, and precipitation processes.

It is evident that both the infrared and visible cut-off values for the rain area determination method discussed in this study will be dependent on the stage of development of the thunderstorm, as well as the time of year. Hence there would be a need to establish the relationship of these cut-off values for the different stages of a thunderstorm's life cycle, and for different seasons, if this method were to be used operationally.

The derivation of a model for determining cloud-size distribution would be invaluable for meso-scale research, and would provide a systematic and objective record for establishing cloud climatologies.

In years to come, the numerical combination of remote sensing devices, such as radar and satellite data, will undoubtedly give man the tools to develop a better understanding of our atmosphere and its most dramatic displays of convection.

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A. Appendix A
Infrared Calibration Technique

Since the radiometer on board TIROS-N has an output which is a linear function of the sensed radiance. Then:

$$N = GX + I$$

describes the relationship between digital counts (X) and radiance (N), where G and I are channel gain and intercept respectively. The channel gain is calculated by,

$$G = \frac{Nsp - Nt}{Xsp - Xt}$$

where G is the channel gain in radiance per unit count, Nsp is the radiance of space, Nt is the radiance of the internal target, and Xsp and Xt are the mean output count values when the radiometer veiws space and the internal target respectively.

The channel intercept is calculated by,

$$I = Nsp - G * Xsp.$$

In reality the response of the radiometer in the 11 um region is slightly non-linear due to the physical properties of the radiometer. In order to compensate for these non-linearities the radiance of space is taken to be −1.151, as recommended by Schwalb (1978).

The Planck function is then integrated with the spectral response function of the radiometer and evaluated every 3°C in the −70°C to +30°C range. This process gives a digital count value for each temperature. The temperature of each pixel is then found by a linear interpolation on the temperature versus digital count curve.

Appendix B

Sample Output from Program SCAN

```
INFRARED INFORMATION FROM ORBIT  3758  OF SATELLITE TIROS-N ON  JULY  6  1979
 TIME OF    OF FIRST SCAN 22:13:55 Z

 SATELLITE SCANED PENHOLD AT TIME 22:14:26Z,

 LOCATION OF PENHOLD IN GRID
 SCAN   63.      POSITION   42.


 SATELLITE HEADING IS  NORTH

   968.0 SCANS PASSED SINCE SATELLITE LAST CROSSED EQUATOR

  AT LONGITUDE 104.82 DEGREES WEST


 REFERENCE ORBIT  3740

 CROSSED EQUATOR AT LONGITUDE 354.58 DEGREES EAST

 AT TIME 15:31:31 Z


 ORBITAL PERIOD =  102.09171 MIN

 LONGITUDNAL INCREMENT = 25.52          DEGREES TO WEST

 HEIGHT OF SATELLITE AT EQUATOR =  868. KM     RADIUS OF EARTH = 6365. KM

 ORBITAL INCLINATION =  98.95 DEG     SCANNING RATE =360. SCANS PER MINUTE


 SCANNING BEGINS AT   744  AND ENDS AT   866

 OUTPUT TAKES UP 233 TO 320 OF AVAILABLE WIDTH

 SATELLITE SUBPOINT PIXEL NUMBER = 375.00

 DISTANCE BETWEEN SCANS  =  3.31 KM

 SCALING = 7.6737E+01 GRID UNITS PER INCH IN X DIRECTON

 DISTANCE BETWEEN POINTS =  4.28 KM

 SCALING = 5.9346E+01 GRID UNITS PER INCH IN Y DIRECTION

 MAP SCALE =  1 :10.00 MILLION


      DATA FIELD PARAMETERS


           SMOOTHING PARAMETERS

 SMOOTHING OPERATION NUMBER  1     SMOOTHING PARAMETER =  0.75

 MEAN OF FIELD DIFFERENCES  =   1.001
```

STANDARD DEVIATION = 0.723

NUMBER OF SCANS IN WINDOW = 123

SCAN LINES REJECTED DUE TO SYNCH PROBLEM = 6

SCAN LINES REJECTED = 10. 20. 71.
81. 102. 118.

SMOOTHING OPERATION NUMBER 2 SMOOTHING PARAMETER = 0.75

CALIBRATION PARAMETERS

CALIBRATION CURVE :	DATA LEVELS	TEMPERATURES (IN DEG K)
	233.51	200.00
	225.72	215.00
	215.62	230.00
	203.07	245.00
	188.03	260.00
	170.52	275.00
	150.64	290.00
	128.54	305.00

O. BAD DATA POINTS IN DATA FIELD

GRID DIMENSIONS : COLUMNS 1 TO 123 ROWS 1 TO 88

GRID SIZE = 10.82K ELEMENTS

EXTREME VALUES OF DATA FIELD
MINIMUM = -68.7 MAXIMUM = 52.7

NO LATITUDE LONGITUDE LINES GENERATED

OUTLINE PARAMETERS

LAT-LON POINTS FROM UNIT 1

15 GRID COORDINATE POINTS OF OUTLINE TRANSFERRED TO UNIT 16

OUTLINE OCCUPIES BOX CONTAINING SCANS 9. TO 115. AND POSITIONS 6. TO 82.

GRID POINT POSITIONS OF OUTLINE TRANSFERRED TO UNIT 16

Appendix C

Computer Program Listings

C.1 Program SCAN

```
C      PROGRAM SCAN
C
C        PROGRAM TO CDNVERT TIROS-N TAPE INFDRMATION TD A GRIOOED
C          FIELD, GENERATE GRIO POINT LDCATIDNS OF LATITUDE ANO
C          LDNGITUDE LINES FDR USE IN PLDTTING RDUTINES, CALL
C          SMOOTHING AND CALIBRATION SUBROUTINES WHEN NECESSARY,
C          AND TD WRITE DATA FIELD TD TEMPDRARY FILE.
C
C
C        INPUT FRDM   UNITS 1,2 ANO 3 : LATITUOE - LONGITUOE COOROINATES
C                                       DF OUTLINES TO BE COMPUTEO
C                     UNIT 4 : RAW VALUES DF SATELLITE INFORMATION
C                              (PRODUCED BY PROGRAM TAPERD)
C                     UNIT 5 : PRDGRAM PARAMETERS
C
C        DUTPUT TD    UNIT 6 : PRDGRAM PARAMETERS, CALCULATED VALUES,
C                              AND ERROR STATEMENTS
C                     UNIT 7 : AVERAGED CALIBRATIDN CDEFFICIENTS
C                     UNIT 11 : GRID CDDRDINATES DF LATITUDE ANO
C                               LONGITUDE LINES
C                     UNIT 13 : OUTPUT DF DATA FIELD
C                     UNIT 15 : POSTING OF NORTH POLE AND DTHER LOCATIONS
C                     UNIT 16 : GRIO CDORDINATES DF OUTLINES
C                         (UNITS 17, 18 ANO 19 ALSO USEO IF NECESSARY)
C
       LDGICAL*1 LFMT(1) /'*'/
       LOGICAL*1 LA(760)
       INTEGER RORBIT, RQ, RHR, RMIN, RSEC, LOUT2(3)
       INTEGER*2 HSCAN, BSCAN, ESCAN
       REAL LAINC, LOINC, SLAT(500), SLONG(500)
       REAL*8 IROV, POSI, IR, VISIBL, BLANK
       REAL*8 QUAO, EAST, WEST, HEAD, NOR, SOU, POL, MONTH(12)
       DATA PDSI /8HPOSITION/, IR /8HINFRARED/, VISIBL /8H VISIBLE/
       DATA EAST /8H EAST   /, WEST /8H WEST   /
       DATA NDR /8H NORTH  /, SDU /8H SOUTH  /, POL /8H AT PDLE/
       DATA MDNTH /8H JANUARY, 8HFEBRUARY, 8H   MARCH, 8H   APRIL, 8H
      1 MAY, 8H    JUNE, 8H    JULY, 8H  AUGUST, 8HSEPTEMBR, 8H OCTOBER,
      2     8HNOVEMBER, 8HOECEMBER/
C
       COMMDN /TFIELO/ TEMP(301,400)
       COMMON /CALIB/ COF(11)
       CDMMDN /CDNSTD/ PIT2, PIB2, SB, XKB
       COMMON /CONSTS/ RTSC, H, SSPP, SRPM, SINC, CINC
       COMMON /VARI/ RRL
       CDMMDN /VARID/ SCAN(500), PDSN(500)
       COMMON /PLT/ SCALP, SCALS, SCANMN, POSNMN, IPDS, MAXSC, LCHK1,
      1       LOUT1, KINP
C
```

```
C ***************************************************************************
C
C      CONSTANTS AND CHECKS
C
      COMMON /BLOCK/ R, PI, C1, C2, C4, C5
      R = 6367.65
      PI = 3.1415927
      PIT2 = PI * 2.
      PIB2 = PI / 2.
      C1 = PIT2 / 360.0
      C2 = 1.0 / C1
      OATA C3 /2.54/, MZERO /O/, ZERO /O.O/
      SRPM = 360.0
C     EFFECTIVE SRPM
      ESRPM = 120.
C
C         R    = RAOIUS OF EARTH IN KM
C         PI   = PI
C         PIT2 = PI*2
C         PIB2 = PI/2
C         C1   = CONVERSION FACTOR  OEGREES TO RADIANS
C         C2   = CONVERSION FACTOR  RAOIANS TO OEGREES
C         OIGF = OIGITIZING FREQUENCY OF SATELLITE IN DATA VALUES
C                PER SECOND
C         SRPM = SCAN RATE OF SATELLITE IN REVOLUTIONS PER MINUTE
C                (ONE REVOLUTION EQUALS ONE SCAN)
C         C3   = CONVERSION FACTOR  CM TO INCHES
C         C4   = CONVERSION FACTOR (AHVRR RAOIAN SCAN ANGLE TO DATA
C           VALUE POSITION). THE ZERO OEGREE REFERENCE FOR
C           SATELLITE IS OIRECTLY ABOVE THE SUBPOINT AT OATA VALUE
C           SSPP. SCANNING IS RESTRICTEO TO WITHIN 54' OF SATELLITE
C           SUBPOINT FOR TIROS-N / NOAA A-6 SATELLITES.
C           EACH OATA RECORD (EITHER IR OR VISIBLE DATA) CONTAINS
C           699 OATA VALUES (PLUS A SCAN NUMBER). MIDPOINT IS AT
C           DATA VALUE SSPP. THEREFORE, ALL VALUES MEASUREO
C           FROM ZERO DEGREE REFERENCE ARE CONVERTED TO DATA
C           VALUE POSITIONS BY MULTIPLYING BY C4 AND AOOING
C           SSPP. C4 IS INITALIZED IN 'ENTRY EQNS' IN ITERA.
C
C ***************************************************************************
C
C      INPUT OATA
C
C     INPUT DATA IS REAO FROM UNITS 1,2,3,4 AND 5. ALL INPUT OATA IS
C    FORMAT FREE. VALUES ARE OIVIOEO BY BLANKS OR COMMAS. FORTRAN G
C    COMPILER INSERTS MISSING OECIMAL PLACES FOR REAL DATA ANO OELETES
C    UNNECESSARY DECIMAL PLACES  FOR INTEGER DATA INCORRECTLY ENTERED
C
C     THERE ARE ELEVEN READ STATEMENTS FOR UNIT 5
C
C  1 INPUT TYPE AND INCREMENTS
C
C       KINP = INPUT TYPE
C         KINP=O  NO INPUT FROM UNIT 3. USEO TO CHECK POSITIONS OR
C                 OUTPUT LAT-LON LINES ONLY
C         KINP=1  IR DATA FROM FILE SOURCE
C         KINP=2  VISIBLE OATA FROM FILE SOURCE
C         KINP=3  IR DATA FROM MAG TAPE SOURCE
C         KINP=4  VISIBLE OATA FROM MAG TAPE SOURCE
C       BSCAN = SCAN NUMBER TO BEGIN OUTPUT
C       ESCAN = SCAN NUMBER TO ENO OUTPUT
C
C         PARAMETER HSCAN IS REAO OIRECTLY FROM UNIT 3 FOR EACH SCAN.
C       IT REPRESENTS THE NUMBER OF SCANS SINCE FIRST ARRIVAL OF
C       SATELLITE SIGNAL, FROM PROGRAM TAPERD. IF SCAN NUMBER CORRES-
C       PONOING WITH BSCAN IS NOT AVAILABLE FROM UNIT 3, PROGRAM
C       WILL BEGIN REAOING FIRST SCAN AVAILABLE. IF ESCAN
C       IS LARGER THAN THE LAST SCAN TRANSFERRED BY PROGRAM TAPERD-1
C       TO UNIT 3, AN ENO OF FILE MARK WILL BE ENCOUNTEREO. BOTH
C       CASES RESULT IN PROGRAM FAILURE.
C
```

```
C        KB    = POSITION TO BEGIN OUTPUT
C        KE    = POSITION TO END OUTPUT
C
C          LENGTH OF OUTPUT (NUMBER OF COLUMNS) IS GIVEN BY PARAMETER
C                    MAXSC. MAXIMUM LENGTH IS 400 SCANS
C          WIDTH OF OUTPUT (NUMBER OF ROWS) IS GIVEN BY IPOS (AND XPOS).
C         MAXIMUM WIDTH IS 301 POSITIONS, WHICH CORRESPONDS TO
C         SLIGHTLY LESS THAN ONE HALF THE SCAN WIDTH.
C         SIZE OF OUTPUT IS GIVEN BY MTMAT (MAXSC*IPOS).
C
C        SF     = MAP SCALING FACTOR (1:10,000,000 INPUTTED AS 10E6)
C
C   2 ORBITAL DATA
C
C        NORBIT = NUMBER OF ORBIT
C        NYR   = YEAR OF ORBIT
C        NMO   = MONTH OF ORBIT
C        NDY   = DAY OF ORBIT
C        GRID = NUMBER OF SCANS BETWEEN LAST EQUATOR CROSSING AND
C               FIRST ARRIVAL OF SATELLITE
C
C   3 ORBITAL DATA FOR REFERENCE ORBIT
C
C        RORBIT = NUMBER OF REFERENCE ORBIT
C        RHR     = HOUR OF REFERENCE ORBIT (Z)
C        RMIN    = MINUTE OF REFERENCE ORBIT
C        RSEC    = SECOND OF REFERENCE ORBIT
C        RQ      = QUADRANT OF REFERENCE ORBIT EQUATOR CROSSING
C          RQ=0 (5)  0 TO 90 DEGREES LONGITUDE WEST
C          RQ=1 (6)  90 TO 180 DEGREES LONGITUDE WEST
C          RQ=2 (7)  90 TO 180 DEGREES LONGITUDE EAST
C          RQ=3 (8)  0 TO 90 DEGREES LONGITUDE EAST
C            0,1,2,3 ARE QUADRANTS FOR NORTHERN HEMISPHERE
C            5,6,7,8 ARE QUADRANTS FOR SOUTHERN HEMISPHERE
C        RLONG   = 'LONGITUDE' OF REFERENCE ORBIT EQUATOR CROSSING
C          RQ AND RLONG ARE CODED VALUES READ DIRECTLY FROM T-BUS.
C          THE PROGRAM CALCULATES RLONGC FROM THESE VALUES BY ASSUMING
C          RIGHT ASCENSION OF THE ORBIT, THAT IS, LONGITUDE IS TAKEN
C          TO BE POSITIVE TO EAST AND NEGATIVE TO WEST (T-BUS CODE
C          ASSUMES 0 TO 180 DEGREES BOTH EAST AND WEST)
C
C   4 SATELLITE PARAMETERS
C
C        PER   = ORBITAL PERIOD IN MINUTES
C        REG   = LONGITUDNAL DISPLACEMENT PER ORBIT IN DEG LONG TO WEST
C        H     = HEIGHT OF SATELLITE AT FIRST SCAN IN KM
C        ORIN = INCLINATION OF SATELLITE AT FIRST SCAN IN DEGREES
C        SSPP = SATELLITE SUB-POINT PIXEL NUMBER (NADIR POINT IN SCAN)
C
C   5 CHECKING PARAMETERS
C
C        LCHK1 = FIRST LATITUDE-LONGITUDE CHECKING PARAMETER
C          LCHK1=0  LAT-LON LINES ARE NOT COMPUTED
C          LCHK1=1  LAT-LON LINES ARE COMPUTED
C        LOUT1  = OUTLINE CHECKING PARAMETER
C           LOUT1=0  NO OUTLINES ARE COMPUTED
C           LOUT1=1,2 OR 3  ONE, TWO OR THREE OUTLINES ARE COMPUTED
C              (MAXIMUM OF THREE OUTLINES ALLOWED)
C
C   6 OUTLINE TYPE (NOT REQUIRED IF LOUT1=0)
```

```
C     NOTE : EACH OUTLINE REQUIRES A SEPARATE LOUT2 PARAMETER
C
C        LOUT2 = OUTLINE TYPE PARAMETER
C          LOUT2=1 INPUTTED POINTS OUTPUTTED TO UNIT 6.
C                  CALCULATED GRID POINT LOCATIONS OUTPUTTED
C                  TO UNIT 16 (17,18 AND 19)
C          LOUT2=2 NO OUTPUT OF INPUTTED POINTS.
C                  CALCULATED GRID POINT LOCATIONS OUTPUTTED
C                  TO UNIT 16 (17,18 AND 19). MAXIMUM AND
C                  MINIMUM ROW AND COLUMN OF GRID LOCATIONS
C                  CALCULATED AND OUTPUTTED
C          LOUT2=3 NO OUTPUT OF INPUTTED POINTS.
C                  MAXIMUM AND MINIMUM ROW AND COLUMN OF
C                  GRID LOCATIONS CALCULATED AND OUTPUTTED
C          LOUT2=4 INPUTTTED POINTS OUTPUTTED TO UNIT 6.
C                  CALCULATED GRID POINT LOCATIONS OUTPUTTED
C                  TO UNIT 15 FOR POSTING
C          LOUT2=5 INPUTTED POINTS WITHIN GRID FIELD OUTPUTTED TO UNIT 6.
C                  CALCULATED GRID POINT LOCATIONS OUTPUTTED
C                  TO UNIT 6
C
C  7 LATITUDE AND LONGITUDE INCREMENTS (NOT REQUIRED IF LCHK1=0)
C
C        LAINC = INCREMENT FOR LATITUDE LINES (IN DEGREES)
C        LOINC = INCREMENT FOR LONGITUDE LINES (IN DEGREES)
C        LCHK2 = SECOND LATITUDE-LONGITUDE CHECKING PARAMETER
C          LCHK2=0  DEFAULT VALUES FOR LATITUDE AND LONGITUDE
C                   PLOTTING USED
C          LCHK2=1  VALUES FOR LATITUDE AND LONGITUDE PLOTTING
C                   MUST BE INPUTTED
C
C        THE DEFAULT VALUES ARE LATITUDES FROM 0 TO 90 DEGREES NORTH,
C        LONGITUDES FROM 0 TO 360 DEGREES EAST. POINTS ARE CALCULATED
C        FOR EVERY LATITUDE-LONGITUDE INTERSECTION, BUT IF THE
C        OUTPUTTED AREA IS SMALL, MOST OF THESE POINTS ARE NOT USED.
C        THEREFORE, JUDICIOUS CHOICE OF LATITUDE AND LONGITUDE
C        PARAMETERS LEADS TO GREAT TIME SAVING
C
C  8 LATITUDE AND LONGITUDE PLOTTING VALUES
C     (NOT REQUIRED IF LCHK1=0 OR LCHK2=0)
C
C        LAB  = LATITUDE TO BEGIN PLOTTING
C        LAE  = LATITUDE TO END PLOTTING
C        LOB  = LONGITUDE TO BEGIN PLOTTING
C        LOE  = LONGITUDE TO END PLOTTING
C        LHEM = LONGITUDE HEMISPHERE
C          LHEM=1  BOTH LONGITUDES INPUTTED AS DEGREES EAST
C          LHEM=2  BOTH LONGITUDES INPUTTED AS DEGREES WEST
C
C         LATITUDES ARE EXPRESSED IN DEGREES NORTH
C         LONGITUDES ARE EXPRESSED IN DEGREES EAST OR WEST
C        NOTE: LATITUDE (LONGITUDE) TO BEGIN PLOTTING MUST
C        BE SMALLER THAN LATITUDE (LONGITUDE) TO END PLOTTING
C
C          A MAXIMUM OF 500 POINTS ALLOWED FOR EACH LINE
C
C  9 DATA INPUT PARAMETERS (NOT REQUIRED IF KINP=0)
C
C        NSKIP = NUMBER OF SCANS OF INPUT TO BE SKIPPED (FOR USE WITH MAG
C                TAPE INPUT ONLY. FOR FILE INPUT, PROGRAM WILL READ EACH
```

```
C                 SCAN OF DATA, AND BEGIN OUTPUT WHEN BSCAN IS REACHED)
C
C        LSMT  = SMOOTHING CHECKING PARAMETER
C           LSMT=0  NO SMOOTHING IS DONE
C           LSMT=1  SMOOTHING IS CARRIED OUT
C        LCAL  = CALIBRATION CHECKING PARAMETER
C           LCAL=0  NO CALIBRATION IS DONE
C           LCAL=1  CALIBRATION IS CARRIED OUT
C                   COEFFICIENTS MUST BE READ IN ON UNIT 7.
C
C 10 SMOOTHING PARAMETERS (NOT REQUIRED IF KINP=0 OR LSMT=0)
C           (SEE SUBROUTINE SMOO)
C
C
C     THERE IS ONE READ STATEMENT FOR UNIT 4, WHICH IS CALLED
C    ESCAN-BSCAN+1 TIMES. UNIT 4 IS EITHER A FILE OR A MAG TAPE UNIT.
C
C
C     THERE IS ONE READ STATEMENT FOR UNITS 1, 2 AND 3. EACH CARD OR
C    LINE OF EACH UNIT CONSISTS OF A SINGLE LATITUDE-LONGITUDE
C    INTERSECTION WHICH THE PROGRAM CONVERTS TO GRID POINT COORDINATES.
C    THE PROGRAM CONTINUES TO READ UNTIL 500 POINTS ARE INPUTTED OR
C    AN END OF FILE MARK IS ENCOUNTERED. DEPENDING ON LOUT2,
C    GRID COORDINATES OF THE OUTLINE ARE OUTPUTTED EITHER TO
C    UNIT 6 OR TO UNIT 16 (17,18 AND 19). THIS OUTLINE CAN
C    THEN USED WITH THE GRID FIELD IN PLOTTING
C
C       XLATD = LATITUDE COORDINATE OF POINT (IN DEGREES)
C       XLATM = LATITUDE COORDINATE OF POINT (AND MINUTES)
C       XLOND = LONGITUDE COORDINATE OF POINT (IN DEGREES)
C       XLONM = LONGITUDE COORDINATE OF POINT (AND MINUTES)
C       LHEM  = LONGITUDE HEMISPHERE
C          LHEM=1  LONGITUDE INPUTTED IN DEGREES EAST
C          LHEM=2  LONGITUDE INPUTTED IN DEGREES WEST
C
C **********************************************************************
C
      READ (5,LFMT) KINP, BSCAN, ESCAN, KB, KE, SF
      READ (5,LFMT) NORBIT, NYR, NMO, NDY, GRID
      READ (5,LFMT) RORBIT, RHR, RMIN, RSEC, RQ, RLONG
      READ (5,LFMT) PER, REG, H, ORIN, SSPP
      READ (5,LFMT) LCHK1, LOUT1
      IF (LOUT1 .GT. 0) READ (5,LFMT) (LOUT2(I),I=1,LOUT1)
      IF (LCHK1 .EQ. 0) GO TO 10
      READ (5,LFMT) LAINC, LOINC, LCHK2
      IF (LCHK2 .EQ. 0) GO TO 50
      READ (5,LFMT) LAB, LAE, LOB, LOE, LHEM
   10 IF (KINP .NE. 0) READ (5,LFMT) NSKIP, LSMT, LCAL
      IF (LCAL .EQ. 1) READ (7,LFMT) (COF(I),I=1,11)
C
C
C
C
C        CONVERT LONGITUDE TO DEGREES EAST AND CONVERT
C        BEGINNING AND ENDING LATITUDES AND LONGITUDES
C        TO VALUES USED IN DO LOOPS
      IF (LCHK1 .EQ. 0) GO TO 60
      IF (LAE .LT. LAB) GO TO 820
   20 LAB = LAB * 10 + 10
      LAE = LAE * 10 + 10
```

```
      IF (LOE .LT. LOB) GO TO 840
   30 IF (LHEM .NE. 2) GO TO 40
      LOST = LOE
      LOE = 360 - LOB
      LOB = 360 - LOST
   40 LOB = LOB * 10 + 10
      LOE = LOE * 10 + 10
      GO TO 60
   50 LAB = 10
      LAE = 910
      LOB = 10
      LOE = 3610
C
C           DETERMINE OUTPUT TYPE
   60 IF (KINP .LT. 0 .OR. KINP .GT. 4) GO TO 860
      IROV = POSI
      IF (KINP .EQ. 1 .OR. KINP .EQ. 3) IROV = IR
      IF (KINP .EQ. 2 .OR. KINP .EQ. 4) IROV = VISIBL
C
C         CALCULATE PROGRAM CONSTANTS FROM INPUT PARAMETERS
C
      IF (RQ .EQ. 0 .OR. RQ .EQ. 5) RLONGC = 360. - RLONG
      IF ((RQ .EQ. 1 .OR. RQ .EQ. 6) .AND. RLONG .GE. 90.)
     1RLONGC = 360. - RLONG
      IF ((RQ .EQ. 1 .OR. RQ .EQ. 6) .AND. RLONG .LT. 90.)
     1RLONGC = 360. - RLONG - 100.
      IF ((RQ .EQ. 2 .OR. RQ .EQ. 7) .AND. RLONG .LT. 90.)
     1RLONGC = RLONG + 100.
      IF ((RQ .EQ. 2 .OR. RQ .EQ. 7) .AND. RLONG .GE. 90.)
     1RLONGC = RLONG
      IF (RQ .EQ. 3 .OR. RQ .EQ. 8) RLONGC = RLONG
C           CALCULATE LONGITUDE OF LAST EQUATOR CROSSING
      RL = RLONGC - (NORBIT - RORBIT) * REG
      RL = AMOD(RL,360.0)
      IF (RL .LT. 0.0) RL = RL + 360.0
      RRL = RL * C1
C           CONVERT TO EAST-WEST LONGITUDE FOR OUTPUT ONLY
      QUAD = EAST
      RLOUT = RL
      IF (180.0 - RL) 70, 80, 90
   70 QUAD = WEST
      RLOUT = 360. - RL
      GO TO 90
   80 QUAD = BLANK
C           DETERMINE TIME AT FIRST OUTPUTTED SCAN OF ORBIT
   90 RTIME = RHR * 60. + RMIN + RSEC / 60.
      STIME = RTIME + (NORBIT - RORBIT) * PER + (GRID + BSCAN) / SRPM
      SHR = AMOD(STIME,1440.0)
      IF (SHR .LT. 0.0) SHR = SHR + 1440.0
      NHR = SHR / 60.
      TIMIN = SHR - NHR * 60.
      NMIN = TIMIN
      SSEC = TIMIN - NMIN
      NSEC = SSEC * 60.
      XKB = FLOAT(KB)
C           DETERMINE GRID LENGTH, WIDTH AND SIZE OF FINAL OUTPUT
      IPOS = (KE - KB) + 1
      XPOS = FLOAT(IPOS)
      MAXSC = ESCAN - BSCAN + 1
      IF (KINP .EQ. 0) GO TO 100
```

```
      IF (MAXSC .GT. 400) GO TO 900
      IF (IPOS .GT. 301) GO TO 920
      MTMAT = MAXSC * IPOS
      RTMAT = MTMAT / 1000.
      SCANMN = 0.0
      POSNMN = 0.0
C        DETERMINE NUMBER OF SCANS PER RADIAN OF ORBIT,
C        AND CONVERT BSCAN AND ESCAN TO RADIAN ANGLES
  100 RTSC = PER * ESRPM / (PIT2)
      SB = (BSCAN + GRID) / RTSC
      SE = (ESCAN + GRID) / RTSC
C        DETERMINE LIMITS FOR POSITIONS AND SCANS OF LAT-LON LINES
      DPOS = 0.050 * XPOS
      PB1 = 1.0 - DPOS
      PB2 = PB1 - 2. * DPOS
      PE1 = XPOS + DPOS + 1
      PE2 = PE1 + 2 * DPOS
      DSCAN = 0.050 * (SE - SB)
      SB1 = SB - DSCAN
      SB2 = SB1 - 2. * DSCAN
      SB3 = SB2 - 2. * DSCAN
      SE1 = SE + DSCAN
      SE2 = SE1 + 2. * DSCAN
      SE3 = SE2 + 2. * DSCAN
C        DETERMINE SATELLITE HEADING
      HEAD = POL
      IF (SB .LT. PIB2 .AND. SE .LT. PIB2) HEAD = NOR
      IF (SB .GT. PIB2 .AND. SE .GT. PIB2) HEAD = SOU
C        DETERMINE SCALING FACTORS (IN GRID UNITS PER INCH)
C        THESE FACTORS DUE TO FACT THAT PIXELS ARE NOT SQUARE.
      SF = SF * 1E-6
      SCALP = SF * 10. * C3 * 0.233645
      SCALS = SF * 10. * C3 * 0.302115
      DISTS = 3.31
      DISTP = 4.28
C     DETERMINE IF OUTPUT WIDTH IS TO WIDE.
      IF (XPOS/SCALP .GT. 32.) GO TO 920
C        SATELLITE INCLINATION
  110 RINC = (ORIN) * C1
      SINC = SIN(RINC)
      CINC = COS(RINC)
C
C
C      COMPUTE SCAN LINE # AND TIME PENHOLD WAS SCANNED.
C      PENHOLD COORDINATES  52.2 N  246.1 DEGREES EAST
       MCHK = 0
       PLAT = 52.2
       PLONG = 246.1
       CALL EQNS(REG)
       CALL ITERL(PLAT)
       CALL ITERA(PLONG,PSCAN,PPOSN,MCHK,SB2,SB3,SE2,SE3,PB2,PE2)
C            PSCAN IS THE SCAN OVER PENHOLD
C
C            TIME CALCULATIONS
      TPSC = PSCAN / ESRPM
      NPHR = (SHR+TPSC) / 60.
      PMIN = (SHR+TPSC) - NPHR * 60.
      NPMIN = PMIN
      PSEC = PMIN - NPMIN
      NPSEC = PSEC * 60.
```

/

```
C          PRINT INPUT OATA ANO PRELIMINARY CALCULATIONS
       WRITE (6,120) IROV, NORBIT, MONTH(NMO), NOY, NYR, NHR, NMIN, NSEC,
      1 NPHR, NPMIN, NPSEC, PSCAN, PPOSN, HEAD,GRIO,
      1 RLOUT, QUAO, RORBIT, RLONGC, RHR, RMIN, RSEC,
      2 PER, REG, H, R, ORIN, SRPM
       WRITE (6,130) BSCAN, ESCAN, KB, KE, SSPP, DISTS, SCALS, OISTP,
      1SCALP, SF
   120 FORMAT (1H1, /, 4X, A8, 1X, 'INFORMATION FROM ORBIT', I6, 2X,
      1'OF SATELLITE TIROS-N ON',2X, A8, 1X, I2, 2X, I4, /,5X, 'TIME OF
      2 OF FIRST SCAN',
      2 I3, 1H:, I2, 1H:, I2, 2H Z, //, 5X,
      1'SATELLITE SCANED PENHOLD AT TIME',I3,1H:,I2,1H:,I2,2HZ,//,
      15X,'LOCATION OF PENHOLD IN GRIO',/,5X,'SCAN',F6.0,5X,
      1 'POSITION',
      2 F6.0, ///, 5X, 'SATELLITE HEADING IS ',
      3 A8, //,5X, F7.1, ' SCANS PASSED SINCE SATELLITE
      3 LAST CROSSED EQUATOR',
      4 //,5X,' AT LONGITUDE', F7.2, ' OEGREES', A8, ///,
      1 5X,'REFERENCE ORBIT',
      5 I6,//,5X,'CROSSEO EQUATOR AT LONGITUOE', F7.2, ' OEGREES
      6 EAST',//,5X,'AT TIME',I3, 1H:, I2, 1H:, I2, 2H Z,///, 5X,
      1'ORBITAL PERIOO = ',
      7  F10.5,' MIN',//,5X,'LONGITUONAL INCREMENT =', F6.2, '
      8OEGREES TO WEST', //, 5X, 'HEIGHT OF SATELLITE AT EQUATOR =',
      9        F6.0, ' KM', 5X, 'RAOIUS OF EARTH =', F6.0, ' KM', //, 5X,
      *        'ORBITAL INCLINATION =', F7.2, ' OEG', 5X, 'SCANNING RATE =
      1', F4.0, ' SCANS PER MINUTE')
   130 FORMAT (1H-,/,5X,'SCANNING BEGINS AT', I6, 2X, 'AND ENDS AT', I6,
      1        //,5X,'OUTPUT TAKES UP',I4,' TO', I4, ' OF AVAILABLE WIDTH
      2', //, 5X, 'SATELLITE SUBPOINT PIXEL NUMBER =', F7.2, //, 5X, 'OIS
      3TANCE BETWEEN SCANS  =', F6.2, 1X,
      4'KM',//,5X,'SCALING =', 1PE11.4, ' GRIO UNITS PER INCH IN X OIRECTI
      1ON',//,5X,'OISTANCE BETWEEN POINTS =',OPF6.2,' KM',//,5X,
      1 'SCALING =',
      2 1PE11.4, ' GRIO UNITS PER INCH IN Y OIRECTION', //, 5X,
      3'MAP SCALE =  1 :', OPF5.2, ' MILLION')
C
       IF (KINP .EQ. O) GO TO 290
C       *****************************************************************
C
C    INPUT LOOP FOR OATA FIELO
C
C          SKIP NSKIP SCANS OF DATA (FOR MAG TAPE ONLY)
       IF (KINP .EQ. 3 .OR. KINP .EQ. 4) CALL SKIP(O, NSKIP, 4, &940)
C          REAO ANO INPUT SCANS BETWEEN BSCAN ANO ESCAN
   150 REAO (4,END=1220) HSCAN, LA
       IF (HSCAN .LT. BSCAN) GO TO 150
       IF (HSCAN .GT. ESCAN) GO TO 170
       MSCAN = HSCAN - BSCAN + 1
       ICNT = O
       DO 160 JP = KB, KE
         ICNT = ICNT + 1
         OATUM = FLOAT(IBYTE(LA(JP)))
         IF (DATUM .LT. 1.) OATUM = 1.OE35
         TEMP(ICNT,MSCAN) = DATUM
   160 CONTINUE
       IF (ICNT .NE. IPOS) GO TO 960
       GO TO 150
   170 IF (MAXSC - MSCAN) 980, 180, 980
   180 WRITE (6,190)
```

```
  190 FORMAT (1H-, /, 10X, 'DATA FIELD PARAMETERS')
C     ****************************************************************
C
C       SMOOTHING OF DATA FIELD
C
      IF (LSMT .EQ. 0) GO TO 200
      CALL SMOO(MAXSC, IPOS)
      GO TO 220
C
  200 WRITE (6,210)
  210 FORMAT (1H-, 14X, 'NO SMOOTHING OF DATA FIELD USED')
C     ****************************************************************
C
C       CALIBRATION OF DATA FIELD
C
  220 IF (LCAL .EQ. 0) GO TO 230
      CALL CALI(MAXSC, IPOS, &250, &230)
C
  230 WRITE (6,240)
  240 FORMAT (1H-, 14X, 'NO CALIBRATION OF DATA FIELD USED')
C     ****************************************************************
C
C     WRITE CALIBRATED FIELD TO UNIT 13
C
  250 WRITE (13) IPOS, MAXSC
      DO 260 JJ = 1, MAXSC
  260 WRITE (13) (TEMP(II,JJ),II=1,IPOS)
C
C     CHECK DATA FIELD FOR MAX AND MIN VALUES.
C
      TMIN = 500.0
      TMAX = -500.0
C       FIND MAXIMUM AND MINIMUM OF DATA FIELD
      DO 270 JJ = 1, MAXSC
        DO 270 II = 1, IPOS
          IF (TEMP(II,JJ) .LT. TMIN) TMIN = TEMP(II,JJ)
          IF (TEMP(II,JJ) .GT. TMAX) TMAX = TEMP(II,JJ)
  270 CONTINUE
      WRITE (6,280) MAXSC, IPOS, RTMAT, TMIN, TMAX
  280 FORMAT (1H-, //, 5X, 'GRID DIMENSIONS :  COLUMNS  1  TO', I5, 5X,
     1        'ROWS 1 TO', I5, //, 5X, 'GRID SIZE =', F6.2, 'K ELEMENTS',
     2        //, 5X, 'EXTREME VALUES OF DATA FIELD', /, 5X, 'MINIMUM =',
     3        F6.1, 5X, 'MAXIMUM =', F6.1)
C
  290 IF (LCHK1 .EQ. 0) GO TO 490
C     ****************************************************************
C
C       DETERMINE INCREMENTS FOR FINDING LATITUDE AND LONGITUDE CURVES
C             (INCREMENTS MUST BE AT LEAST 1)
C
      LALAT = LAINC * 10
      IF (LALAT .LT. 1) LALAT = 1
      LOLAT = LAINC * 2
      IF (LOLAT .LT. 1) LOLAT = 1
      LOLON = LOINC * 10
      IF (LOLON .LT. 1) LOLON = 1
      LALON = LOINC * 1
      IF (LALON .LT. 1) LALON = 1
      WRITE (6,300) LAINC, LOINC
  300 FORMAT (1H-, /, 10X, 'LATITUDE-LONGITUDE PARAMETERS', ///, 5X, 'LA
```

```
          1TITUDE  LINES GENERATED EVERY', F5.1, ' DEGREES', 5X, '500 POINTS
          2ALLOWED FOR EACH LINE', //, 5X, 'LONGITUDE LINES GENERATED EVERY',
          3        F5.1, ' DEGREES', 5X, '500 POINTS ALLOWED FOR EACH LINE')
C
C
C     *****************************************************************
C     *****************************************************************
C
C     OUTLINES AND LATITUDE, LONGITUDE LINE COMPUTATIONS.
C        (THE FOLLOWING MAY BE SIGNIFICANTLY SIMPLIFIED BY
C         RESTRICTING THE INPUT-OUTPUT OPTIONS.)
C
      CALL EQNS(REG)
      JUNIT = 11
      WRITE (6,310) JUNIT
  310 FORMAT (1H-, 14X, 'LATITUDE-LONGITUDE LINES OUTPUTTED TO UNIT',
     1        I4)
      KCHK = 0
C      ****************************************************************
C
C       DETERMINE POINTS FOR LATITUDE LINES
C
      WRITE (6,320)
  320 FORMAT (1H0, 7X, 'LATITUDE LINES', /)
      MLL = 1
C        MLL=1 DENOTES LATITUDE LINES IN OUTPUT
C
C        INCREMENT LATITUDE LINES TO BE FOUND
      DO 390 LAT = LAB, LAE, LALAT
        ALAT = (LAT - 10) / 10.
        LLAT = IFIX(ALAT)
        LOLATA = LOLAT
C        ONLY ONE-FIFTH NUMBER OF POINTS USED IN
C        LATITUDE LINES NORTH OF 80 DEGREES
        IF (ALAT .GT. 80.) LOLATA = 5 * LOLAT
        IF (ALAT .GT. 90.) GO TO 1060
        MM = 1
C
C        INCREMENT LONGITUDE INTERSECTIONS TO DETERMINE
C        EACH LATITUDE LINE
        CALL ITERL(ALAT)
        DO 340 LONG = LOB, LOE, LOLATA
          BLONG = (LONG - 10) / 10.
          CALL ITERA(BLONG, SCAN(MM), POSN(MM), MCHK, SB1, SB2, SE1,
     1          SE2, PB1, PE1)
          IF (MCHK .EQ. 1) GO TO 330
          IF (MM .EQ. 1) GO TO 340
          KCHK = KCHK + 1
          GO TO 350
  330     IF (SCAN(MM) .LT. SCANMN) SCANMN = SCAN(MM)
          IF (SCAN(MM) .GT. SCANMX) SCANMX = SCAN(MM)
          IF (POSN(MM) .LT. POSNMN) POSNMN = POSN(MM)
          IF (POSN(MM) .GT. POSNMX) POSNMX = POSN(MM)
          MM = MM + 1
  340   CONTINUE
  350   MM = MM - 1
        IF (MM .LE. 2) GO TO 390
C        OUTPUT LATITUDE LINE SEGMENT
        WRITE (6,360) ALAT, MM
  360   FORMAT (1H , 5X, 'LATITUDE =', F5.1, ' DEGREES NORTH', 6X, 'POIN
```

```
     1TS IN LATITUDE LINE =', I4)
        WRITE (JUNIT,370) MM, MZERO, MLL, LLAT
  370   FORMAT (4I4)
        WRITE (JUNIT,380) (SCAN(I),POSN(I),I=1,MM)
  380   FORMAT (2F7.2)
        KCHK = KCHK + 1
  390 CONTINUE
  400 FORMAT (3F7.2)
C
C *******************************************************************
C
C       DETERMINE POINTS FOR LONGITUDE LINES
C
  410 WRITE (6,420)
  420 FORMAT (1HO, 7X, 'LONGITUDE LINES', /)
      MLL = 2
C        MLL=2 DENOTES LONGITUDE LINES IN OUTPUT
C
C        INCREMENT LONGITUDE LINES TO BE FOUND
      DO 470 LONG = LOB, LOE, LOLON
        ALONG = (LONG - 10) / 10.
        LLONG = IFIX(ALONG)
        IF (ALONG .GT. 360.) GO TO 1080
        VLONG = ALONG / (2.*LOLON) - IFIX(ALONG/(2.*LOLON))
        MM = 1
C
C        INCREMENT LATITUDE INTERSECTIONS TO DETERMINE
C        EACH LONGITUDE LINE
        DO 440 LAT = LAB, LAE, LALON
          BLAT = (LAT - 10) / 10.
C        EXTEND ONLY EVERY SECOND LONGITUDE LINE
C        PAST 85 DEGREES NORTH TO AVOID CROWDING
          IF (BLAT .GT. 85. .AND. VLONG .GT. 0.1) GO TO 470
          CALL ITERL(BLAT)
          CALL ITERA(ALONG, SCAN(MM), POSN(MM), MCHK, SB2, SB3, SE2,
     1          SE3, PB2, PE2)
          IF (MCHK .EQ. 1) GO TO 430
          IF (MM .EQ. 1) GO TO 440
          KCHK = KCHK + 1
          GO TO 450
  430     IF (SCAN(MM) .LT. SCANMN) SCANMN = SCAN(MM)
          IF (SCAN(MM) .GT. SCANMX) SCANMX = SCAN(MM)
          IF (POSN(MM) .LT. POSNMN) POSNMN = POSN(MM)
          IF (POSN(MM) .GT. POSNMX) POSNMX = POSN(MM)
          MM = MM + 1
  440   CONTINUE
  450   MM = MM - 1
        IF (MM .LE. 2) GO TO 470
C        OUTPUT LONGITUDE LINE SEGMENT (ONLY ONE SEGMENT
C          POSSIBLE FOR EACH LONGITUDE LINE)
        WRITE (6,460) ALONG, MM
  460   FORMAT (1H , 5X, 'LONGITUDE =', F6.1, ' DEGREES EAST', 5X, 'POIN
     1TS IN LONGITUDE LINE =', I4)
        WRITE (JUNIT,370) MM, MZERO, MLL, LLONG
        WRITE (JUNIT,380) (SCAN(I),POSN(I),I=1,MM)
  470 CONTINUE
C
      WRITE (6,480) KCHK, JUNIT, SCANMN, SCANMX, POSNMN, POSNMX
  480 FORMAT (1HO, 7X, I4, ' LATITUDE-LONGITUDE LINES OUTPUTTED TO UNIT'
     1       , I3, //, 5X, 'LAT LON LINES FORM BOX : COLUMNS', F5.0, 'TO
```

```
     2', F5.0, 5X, 'ROWS', F5.0, 'TO', F5.0)
      GO TO 510
C
  490 WRITE (6,500)
  500 FORMAT (1H-, /, 10X, 'NO LATITUDE LONGITUDE LINES GENERATED')
C     *****************************************************************
C
C        DETERMINE GRID COORDINATES OF INPUTTED LAT-LON POINTS
C
  510 IF (LOUT1 .EQ. 0) GO TO 790
      MLL = 3
C         MLL=3 DENOTES OUTLINE IN OUTPUT
      WRITE (6,520)
  520 FORMAT (1H-, /, 10X, 'OUTLINE PARAMETERS', //)
C
      KUNIT = 16
      CALL EQNS(REG)
      DO 780 LUNIT = 1, LOUT1
        IF (LUNIT .GT. 3) GO TO 1100
        WRITE (6,530) LUNIT
  530   FORMAT (1H , 14X, 'LAT-LON POINTS FROM UNIT', I3, /)
        IF (LOUT2(LUNIT) .LT. 1 .OR. LOUT2(LUNIT) .GT. 5) GO TO 1140
C
        IF (KUNIT .GT. 19) GO TO 1040
        II = 0
        MM = 0
        KCHK = 0
C         INPUT LOOP FOR LAT-LON OUTLINE INTERSECTIONS
  540   II = II + 1
        MM = MM + 1
        MCHK = 0
        READ (LUNIT,LFMT,END=660,ERR=1120) XLATD, XLATM, XLOND, XLONM,
     1  LHEM
        SLAT(II) = XLATD + XLATM / 60.0
        SLONG(II) = XLOND + XLONM / 60.0
        IF (LHEM .EQ. 2) SLONG(II) = 360.0 - SLONG(II)
        CALL ITERL(SLAT(II))
        CALL ITERA(SLONG(II), SCAN(MM), POSN(MM), MCHK, SB2, SB3, SE2,
     1       SE3, PB2, PE2)
        IF (MCHK .EQ. 1 .OR. MM .LE. 1) GO TO 540
        IF (LOUT2(LUNIT) .EQ. 3) GO TO 1200
C         OUTPUT OUTLINE SEGMENT
        KCHK = KCHK + 1
        MM = MM - 1
        IF (LOUT2(LUNIT) - 4) 550, 580, 600
  550   WRITE (6,560) MM, KUNIT
  560   FORMAT (1H0, 4X, I4, ' GRID COORDINATE POINTS OF OUTLINE', ' TRA
     1NSFERRED TO UNIT', I3)
        WRITE (KUNIT,570) MM
  570   FORMAT (I4)
        WRITE (KUNIT,380) (SCAN(I),POSN(I),I=1,MM)
        GO TO 650
  580   WRITE (6,590) MM, KUNIT
  590   FORMAT (1H0, 4X, I4, ' GRID COORDINATE POINTS ', 'CONTAINED IN U
     1NIT', I4, ' OUTPUT AREA ', 'TRANSFERRED TO UNIT 15 FOR POSTING')
        WRITE (15,400) (SCAN(I),POSN(I),ZERO,I=1,MM)
        GO TO 650
  600   WRITE (6,610)
  610   FORMAT (1H0, 4X, 'INPUTTED POINTS', /)
        WRITE (6,620) (SLAT(I),SLONG(I),I=1,MM)
```

```
      620   FORMAT (1H , 8(F6.2,F7.2,3X))
            WRITE (6,630)
      630   FORMAT (1HO, 4X, 'GRID COORDINATES', /)
            WRITE (6,640) (SCAN(I),POSN(I),I=1,MM)
      640   FORMAT (1H , 8(F7.1,F6.1,3X))
      650   MM = O
            GO TO 540
C        END OF OUTLINE FILE GO ON.
      660   II = II - 1
            IF (MCHK .EQ. O .AND. MM .LE. 1) GO TO 740
            KCHK = KCHK + 1
            IF (LOUT2(LUNIT) - 4) 670, 680, 700
      670   IF (LOUT2(LUNIT) .EQ. 3) GO TO 710
            MM = MM - 1
            WRITE (6,560) MM, KUNIT
            WRITE (KUNIT,570) MM
            WRITE (KUNIT,380) (SCAN(I),POSN(I),I=1,MM)
            IF (LOUT2(LUNIT) - 2) 690, 710, 710
      680   WRITE (6,590) MM, KUNIT
            WRITE (15,400) (SCAN(I),POSN(I),ZERO,I=1,MM)
      690   WRITE (6,610)
            WRITE (6,620) (SLAT(I),SLONG(I),I=1,II)
            GO TO 740
      700   WRITE (6,610)
            WRITE (6,620) (SLAT(I),SLONG(I),I=1,MM)
            WRITE (6,630)
            WRITE (6,640) (SCAN(I),POSN(I),I=1,MM)
            GO TO 740
C           DETERMINE MAXIMUM AND MINIMUM SCAN AND POSITION VALUES
C           OF LAT-LON INTERSECTIONS WITHIN EXTENDED LIMITS OF GRID
      710   SCANMN = 1900.
            SCANMX = -1000.
            POSNMN = 1900.
            POSNMX = -1000.
            DO 720 JI = 1, MM
              IF (SCAN(JI) .LT. SCANMN) SCANMN = SCAN(JI)
              IF (SCAN(JI) .GT. SCANMX) SCANMX = SCAN(JI)
              IF (POSN(JI) .LT. POSNMN) POSNMN = POSN(JI)
              IF (POSN(JI) .GT. POSNMX) POSNMX = POSN(JI)
      720   CONTINUE
            WRITE (6,730) SCANMN, SCANMX, POSNMN, POSNMX
      730   FORMAT (1HO, 4X, 'OUTLINE OCCUPIES BOX CONTAINING SCANS', F5.O,
         1          ' TO', F5.O, 4X, 'AND POSITIONS', F5.O, ' TO', F5.O)
C
      740   IF (KCHK .EQ. O) GO TO 1180
            IF (LOUT2(LUNIT) .EQ. 1 .OR. LOUT2(LUNIT) .EQ. 2) WRITE (6,
         1        750) KUNIT
      750   FORMAT (1HO, 4X, ' GRID POINT POSITIONS OF OUTLINE TRANSFERRED
         1 TO UNIT', I4)
            IF (LOUT2(LUNIT) .EQ. 3 .OR. LOUT2(LUNIT) .EQ. 5) GO TO 760
      760   WRITE (6,770)
      770   FORMAT (1HO)
            KUNIT = KUNIT + 1
C
C
      780 CONTINUE
      790 STOP
C
      800 WRITE (6,810)
      810 FORMAT (1H-, /, 10X, 'NO OUTLINES GENERATED', //)
```

```
      GO TO 1240
C       *****************************************************************
C
C         ERROR DEFAULT STATEMENTS
C
C          IN SOME CASES PROGRAM WILL PRINT ERROR AND TRY TO
C          CORRECT FOR IT AUTOMATICALLY.
C
  820 WRITE (6,830)
  830 FORMAT (1HO, '***** ERROR   LATITUDE TO BEGIN PLOTTING', ' GREATER
     1 THAN LATITUDE TO END PLOTTING *****')
      LAST = LAE
      LAE = LAB
      LAB = LAST
      GO TO 20
  840 WRITE (6,850)
  850 FORMAT (1HO, '***** ERROR   LONGITUDE TO BEGIN PLOTTING', ' GREATE
     1R THAN LONGITUDE TO END PLOTTING *****')
      LOST = LOE
      LOE = LOB
      LOB = LOST
      GO TO 30
  860 WRITE (6,870) KINP
  870 FORMAT (1HO, '***** ERROR   INPUT TYPE INCORRECTLY SPECIFIED', 3X,
     1        'KINP =', I3, ' INPUTTED, 0 TO 4 ONLY ALLOWED *****')
      GO TO 1240
  880 WRITE (6,890)
  890 FORMAT (1HO, '***** ERROR   INVALID PARAMETERS FOR WIDTH OF ', 'OU
     1TPUT FIELD *****')
      GO TO 1240
  900 WRITE (6,910) MAXSC
  910 FORMAT (1HO, '***** ERROR   OUTPUT TOO LONG', 5X, I6,
     1        ' SCANS IN ', 'OUTPUT.  FORMAT ALLOWS ONLY 400 SCANS *****'
     2        )
      GO TO 1240
  920 WRITE (6,930) IPOS
  930 FORMAT (1HO, '***** ERROR   OUTPUT TOO WIDE', 5X, I6, ' POSITIONS
     1IN ', 'OUTPUT.  FORMAT ALLOWS ONLY 301 POSITIONS *****')
      GO TO 1240
  940 WRITE (6,950)
  950 FORMAT (1HO, '***** ERROR IN SCAN SKIP *****')
      GO TO 1240
  960 WRITE (6,970) HSCAN
  970 FORMAT (1HO, '***** ERROR   INCORRECT DATA LENGTH FOR SCAN', I6, '
     1 *****')
      GO TO 1240
  980 WRITE (6,990) MSCAN
  990 FORMAT (1HO, '***** ERROR   INCORRECT DATA LENGTH', 5X, I7, ' SCAN
     1S IN OUTPUT *****')
      IF (MSCAN .GT. 400) GO TO 1240
      MAXSC = MSCAN
      GO TO 180
 1000 WRITE (6,1010)
 1010 FORMAT (1HO, '***** ERROR   TOO MANY OUTPUT UNITS CALLED ', 'FOR D
     1ATA FIELD OUTPUT *****')
      GO TO 290
 1020 WRITE (6,1030)
 1030 FORMAT (1HO, '***** ERROR   TOO MANY OUTPUT UNITS CALLED ', 'FOR L
     1AT-LON LINE OUTPUT *****')
      GO TO 490
```

```
 1040 WRITE (6,1050)
 1050 FORMAT (1HO, '***** ERROR   TOO MANY OUTPUT UNITS CALLED ', 'FOR O
     1UTLINE OUTPUT *****')
      GO TO 800
 1060 WRITE (6,1070)
 1070 FORMAT (1HO, '***** ERROR   END VALUE FOR FINAL LATITUDE LINE ', '
     1LARGER THAN 90 DEGREES *****')
      GO TO 410
 1080 WRITE (6,1090)
 1090 FORMAT (1HO, '***** ERROR   END VALUE FOR FINAL LONGITUDE LINE ',
     1        'LARGER THAN 360 DEGREES *****')
      GO TO 1240
 1100 WRITE (6,1110)
 1110 FORMAT (1HO, '***** ERROR   TOO MANY INPUT UNITS CALLED', ' FOR OU
     1TLINE PROCEEDURE *****')
      GO TO 1240
 1120 WRITE (6,1130) LUNIT
 1130 FORMAT (1HO, '***** ERROR IN UNIT', I2, ' READ *****')
      GO TO 1240
 1140 WRITE (6,1150) LOUT2(LUNIT)
 1150 FORMAT (1HO, '***** ERROR   OUTLINE TYPE LOUT2 INCORRECTLY ', 'SPE
     1CIFIED AS', I6, ' *****')
      GO TO 1240
 1160 WRITE (6,1170)
 1170 FORMAT (1HO, '***** ERROR   MORE THAN 500 POINTS IN OUTLINE *****'
     1       )
      GO TO 660
 1180 WRITE (6,1190)
 1190 FORMAT (1HO, '***** ERROR   FAILURE IN OUTLINE PROCEEDURE, NO ', '
     1POINTS FOUND WITHIN GRID LIMITS *****')
      GO TO 1240
 1200 WRITE (6,1210)
 1210 FORMAT (1HO, '***** ERROR   OUTLINE EXCEEDS LIMITS OF ', 'DATA FIE
     1LD *****')
      GO TO 740
 1220 WRITE (6,1230)
 1230 FORMAT (1HO, '****** ERROR END OF FILE ON UNIT 4 ******')
      STOP 99
 1240 STOP
      END
C *********************************************************************
C
      FUNCTION IBYTE(NUM)
C
C       CONVERTS ONE BYTE NUMBER TO TWO BYTE INTEGER
      LOGICAL*1 NUM, INT(2)
      INTEGER*2 I /0/
      EQUIVALENCE (I,INT)
      INT(2) = NUM
      IBYTE = I
      RETURN
      END
END OF FILE
```

C.2 Program TAPERD

```
C          PROGRAM TAPERD
C
C      PROGRAM FOR IDENTIFYING SATELLITE SCAN INFORMATION
C      AND CONVERTING MAG TAPE INFORMATION TO COMPUTER USEABLE FORM
C
C   INPUT FROM   UNIT 1 : RAW TAPE DATA IN ONE BYTE INTEGER FORM
C                UNIT 5 : PROGRAM PARAMETERS
C
C   OUTPUT TO    UNIT 3 : (RAW TAPE DATA IN ONE BYTE FORM)
C                UNIT 6 : PROGRAM PARAMETERS, TAPE DOCUMENTATION,
C                         (TAPE DATA IN INTEGER FORM),
C                UNIT 7 : CALIBRATION WEDGE LEVELS.
C
C          TAPE PARAMETERS
C
C        SPB = NUMBER OF SCANS PER DATA BLOCK  (5)
C        BPS = NUMBER OF BYTES PER SCAN  (1530)
C        LDR = LENGTH OF DATA RECORD (ONE SCAN)
C              (BPS BYTES PLUS TWO BYTES CONTAINING SCAN NUMBER)
C        LDB = LENGTH OF DATA BLOCK (SPB SCANS)
C        LEN = LENGTH OF ANY BLOCK
C        LRN = INTERNAL COUNTER FOR DATA INPUT
C
C          OUTPUT PARAMETERS
C
C        ID(J) = OUTPUT IN INTEGER FORM (UNIT 6)
C        LA(J) = OUTPUT IN ONE BYTE FORM (UNIT 3)
C        NSC(N)= TWO BYTE NUMBER OF SCAN OUTPUTTED
C        MINSC = FIRST SCAN OUTPUTTED
C        MAXSC = LAST SCAN OUTPUTTED
C        NSOUT = NUMBER OF SCANS OUTPUTTED
C *********************************************************************
C
      LOGICAL*1 LFMT(1) /'*'/
      LOGICAL*1 FL(18), DTXT(52), LA(8192)
      INTEGER*2 IA(4096), HTXT(26), LREV/5/, LFWD/3/
      EQUIVALENCE (IA(1),DTXT,HTXT,FL,LA)
      INTEGER*2 LEN, ISC(64), LL(18), DOC(52), NSC(12), ID(2512)
      INTEGER*4 LRN
      INTEGER BPS, SPB, NX(10)
      REAL*8 IROV(2)
C
      DATA IROV /8H      IR , 8HVISIBLE /
C
      DATA ISC /1H , 1H!, 1H", 1H#, 1H$, 1H%, 1H&, 1H', 1H(, 1H), 1H*,
     1     1H+, 1H,, 1H-, 1H., 1H/, 1HO, 1H1, 1H2, 1H3, 1H4, 1H5, 1H6,
     2     1H7, 1H8, 1H9, 1H:, 1H;, 1H., 1H=, 1H>, 1H?, 1H@, 1HA, 1HB,
     3     1HC, 1HD, 1HE, 1HF, 1HG, 1HH, 1HI, 1HJ, 1HK, 1HL, 1HM, 1HN,
     4     1HO, 1HP, 1HQ, 1HR, 1HS, 1HT, 1HU, 1HV, 1HW, 1HX, 1HY, 1HZ,
     5     1H(, 1H/, 1H), 1H|, 1H_/
C
C *********************************************************************
C
C        INPUT DATA IS FORMAT FREE, DIVIDED BY COMMAS
C
C        NFS = NUMBER OF FILES TO BE SKIPPED
C        NBS = NUMBER OF BLOCKS TO BE SKIPPED
C        NBR = NUMBER OF BLOCKS TO BE READ AND OUTPUTTED
C        KOUT= OUTPUT OPTION
```

```
C           KOUT=6  OUTPUTS FORMATTED BLOCKS TO UNIT 6
C           KOUT=3  OUTPUTS UNFORMATTED BLOCKS TO UNIT 3
C                     FILE OR MAG TAPE FOR USE IN PROGRAM
C                     SCAN. IN THE INFRARED CASE THE
C                     TELEMETRY DATA IS OUTPUT TO UNIT 7.
C
C     INPUT DATA: FOR UNIT 3 OUTPUT ONLY
C
C        ITYPE = OUTPUT TYPE OPTION
C          ITYPE=1  OUTPUTS IR DATA
C          ITYPE=2  OUTPUTS VISIBLE DATA
C
C ******************************************************************
C
C          READ TAPE INPUT DATA
      READ (5,LFMT,END=470) NORBIT, NFS, NBS, NBR, KOUT, ITYPE,BPS,SPB
C
      WRITE (6,20)
   20 FORMAT (1H1, 10X, 'INPUT PARAMETERS')
      WRITE (6,30) NFS, NBS, NBR, KOUT
   30 FORMAT (1HO, 5X, 'FILES SKIPPED =', I3, 5X, 'BLOCKS SKIPPED =',
     1       I3, 5X, 'BLOCKS READ =', I4, 5X, 'OUTPUT OPTION =', I2)
C
C          READ UNIT 3 INPUT DATA
      IBGN = O
C     THERE ARE 800 SAMPLES PER CHANNEL(IR&VIS)
      IF (ITYPE .EQ. 2) IBGN = 800
      IF ( KOUT .NE. 6 ) GO TO 50
      WRITE (6,40) IROV(ITYPE)
   40 FORMAT (1HO, 5X, A8, 'INFORMATION TRANSFERRED TO UNIT 3')
C
   50 REWIND 1
C
C        SKIP TO FILE
C
      CALL SKIP(NFS, O, 1, &390)
C
C        READ AND INTERPRET FILE LABEL
C
 96   CALL READ(FL, LEN, O, LRN, 1, &290)
      DO 60 L = 1, LEN
        ID(L) = IBYTE(FL(L))
        INDX = ID(L) - 31
        IF (INDX .LT. 1) INDX = 1
        IF (INDX .GT. 64) INDX = 1
        LL(L) = ISC(INDX)
   60 CONTINUE
C
C          PROGRAM CHECKS FOR CORRECT PASS NUMBER
C          PROGRAM WILL SEARCH TAPE UNTIL IT'S FOUND
      NPASS = LL(2)*1000 + LL(1)*100 + LL(4)*10 +LL(3)
      IF (NPASS-NORBIT) 98,99,97
 97   CALL CNTRL('BSF 2',LREV,1,RET)
 98   CALL CNTRL('FSF',LFWD,1,RET)
      GO TO 96
C
 99   WRITE (6,70) (LL(K),K=1,4), LL(2), LL(1), LL(4), LL(3), LEN, LRN
   70 FORMAT (1HO, 5X, 'FILE LABEL=', 4A1, 5X, 'ORBIT ', 4A1, 5X, 'LENGT
     1H=', I3, 5X, 'LRN=', I5)
C
```

```
C        READ AND INTERPRET FILE DOCUMENTATION
C
   80 CALL READ(DTXT, LEN, 0, LRN, 1, &310)
C      BPS AND SPB ARE READ IN. IF EITHER ARE 0 USE VALUES FROM TAPE.
C      USED IN CASE OF TAPE ERROR
      IF(BPS.GT.0 .AND. SPB.GT.0) GO TO 85
      BPS = HTXT(1)
      SPB = HTXT(2)
85    DO 90 L = 5, LEN
        ID(L) = IBYTE(DTXT(L))
        INDX = ID(L) - 31
        IF (INDX .LT. 1) INDX = 1
        IF (INDX .GT. 64) INDX = 1
        DOC(L) = ISC(INDX)
   90 CONTINUE
      WRITE (6,100) (DOC(K),K=5,LEN), LEN, LRN
  100 FORMAT (1H0, 5X, 'DOCUMENTATION:', 48A1, 5X, 'LENGTH=', I3, 5X, 'L
     1RN=', I5)
      WRITE (6,110) BPS, SPB
  110 FORMAT (1H0, 5X, I5, ' BYTES PER SCAN', 4X, I2, ' SCANS PER BLOCK'
     1      )
      LDR = BPS + 2
      LDB = SPB * LDR
      NS = LDR / 2
C
C        SKIP NBS BLOCKS OF DATA
C
  120 CALL SKIP(0, NBS, 1, &450)
      ISCAN = SPB * NBS
      MINSC = ISCAN
      NSOUT = 0
C
C
C        READ AND CONVERT NBR BLOCKS OF DATA
C
      DO 270 KK = 1, NBR
        NBCNT = NBS + KK
C        READ ONE BLOCK OF DATA
        CALL READ(IA, LEN, 0, LRN, 1, &330)
C       CHECK TO SEE IF BLOCK LENGTH CORRECT (BLOCKS
C         OF INCORRECT LENGTH ARE NOT OUTPUTTED)
        IF (LEN .NE. LDB) GO TO 350
C
        DO 180 N = 1, SPB
          IX = (N - 1) * NS + 1
          NSC(N) = IA(IX)
C       CHECK TO SEE IF SCAN NUMBER CORRECT (MISSED SCANS ARE NOTED)
          IF (NSC(N) .EQ. ISCAN) GO TO 170
          IF (NSC(N) - ISCAN .GT. 1) GO TO 140
          WRITE (6,130) ISCAN
  130     FORMAT (1H0, 5X, 'MISSED SCAN =', I5)
          GO TO 160
  140     NSS = NSC(N) - 1
          WRITE (6,150) ISCAN, NSS
  150     FORMAT (1H0, 5X, 'SCANS', I5, 2X, 'TO', I5, 2X, 'MISSED')
  160     ISCAN = NSC(N)
  170     ISCAN = ISCAN + 1
  180   CONTINUE
        IF (KOUT .NE. 6) GO TO 230
C
```

```
C       UNIT 6 DATA OUTPUT
C
C         WRITE BLOCK DOCUMENTATION
          WRITE (6,190) LEN, LRN, (NSC(N),N=1,SPB)
  190     FORMAT (1HO, 5X, 'DATA BLOCK LENGTH=', I5, 5X, 'LRN=', I5, 5X, '
     1SCANS', 10I5)
C
C       THE FOLLOWING MAY BE USED TO WRITE OUT ONE BLOCK OF DATA.
C         DO 220 I = 1, SPB
C           NJ = (I - 1) * LDR
C           DO 200 J = 1, LDR
C             ID(J) = IBYTE(LA(J + NJ))
C 200       CONTINUE
C        OUTPUT ONE SCAN OF DATA
C       WRITE(6,210)I,J,ID(1),ID(2)
C           WRITE (6,210) (ID(J),J=3,LDR)
C210       FORMAT (20I4)
C           NSOUT = NSOUT + 1
C 220     CONTINUE
        GO TO 270
C
C       UNIT 3 DATA OUTPUT
C
C       NOTE FOR MAG TAPE OUTPUT:  UNIT 1 IS REWOUND
C         AT BEGINNING OF PROGRAM. UNIT 3 IS NOT REWOUND.
C         THEREFORE, SECTIONS OF SEVERAL FILES FROM UNIT 1
C         CAN BE TRANSFERRED TO SUCCESSIVE FILES OF UNIT 3
C         BY RE-RUNNING TAPERD, USING NEW INPUT PARAMETERS FOR
C         EACH RUN
C
230       DO 260 I = 1, SPB
            JB = 3 + (I - 1) * LDR + IBGN
            JE = JB + 759
            WRITE (3) NSC(I), (LA(J),J=JB,JE)
            NSOUT = NSOUT + 1
281         IF (ITYPE .NE. 1) GO TO 260
            JB = JB + 735
            JE = JB + 19
            KKK = 0
            DO 240 NNN = JB, JE
              KKK = KKK + 1
              NX(KKK) = IBYTE(LA(NNN))
  240       CONTINUE
          IF (KK .LT. 5 .OR. KK .GT. 60) GO TO 260
            WRITE (7,250) (NX(KKK),KKK=1,20)
  250       FORMAT (20I4)
  260     CONTINUE
C
  270   CONTINUE
C
C         PRINT OUTPUT PARAMETERS
C
        MAXSC = NSC(SPB)
        WRITE (6,280) MINSC, MAXSC, NSOUT
  280   FORMAT (1HO, 5X, 'FIRST SCAN OUTPUTTED =', I5, 5X, 'LAST SCAN', '
     1OUTPUTTED =', I5, 5X,
     1      'NUMBER OF SCANS OUTPUTTED =', I5)
        IF (KOUT .EQ. 6) GO TO 470
        END FILE 3
C
```

```
      GO TO 470
C ***********************************************************************
C
C        ERROR DEFAULT STATEMENTS
C
  290 WRITE (6,300)
  300 FORMAT (1H0, 5X, '***ERROR IN FILE LABEL INPUT***')
      GO TO 80
  310 WRITE (6,320)
  320 FORMAT (1H0, 5X, '***ERROR IN DOCUMENTATION INPUT***')
      GO TO 120
  330 WRITE (6,340) NBCNT
  340 FORMAT (1H0, 5X, '***ERROR IN RECORD INPUT AT BLOCK', I5, '***')
      STOP
  350 WRITE (6,360) NBCNT, LDB, LEN, LDR, BPS, SPB
  360 FORMAT (1H0, 5X, '***ERROR IN LENGTH OF DATA BLOCK', I5, '***', //
     1       , 5X, 'LDB =', I7, 5X, 'LEN =', I6, 5X, 'LDR =', I6, 5X, 'B
     2PS =', I6, 5X, 'SPB =', I3)
      GO TO 270
  370 WRITE (6,380) NBCNT
  380 FORMAT (1H0, 5X, '***ERROR IN CALIBRATION INPUT BLOCK', I5, '***')
  390 WRITE (6,400)
  400 FORMAT (1H0, 5X, '***ERROR ON FILE SKIP***')
      STOP
  410 WRITE (6,420)
  420 FORMAT (1H0, 5X, '***ERROR ON FIRST FILE RETURN***')
      STOP
  430 WRITE (6,440)
  440 FORMAT (1H0, 5X, '***ERROR ON SECOND FILE RETURN***')
      STOP
  450 WRITE (6,460)
  460 FORMAT (1H0, 5X, '***ERROR ON DATA BLOCK SKIP***')
  470 STOP
      END
C
C
      FUNCTION IBYTE(NUM)
C
C        CONVERTS ONE BYTE NUMBER TO TWO BYTE INTEGER
C
      LOGICAL*1 NUM, INT(2)
      INTEGER*2 I /0/
      EQUIVALENCE (I,INT)
      INT(2) = NUM
      IBYTE = I
      RETURN
      END
END OF FILE
```

C.3 Program TELEM

```
C       PROGRAM TELEM
C
C       DETERMINE AVERAGE DATA VALUES OF CALIBRATION LEVELS
C       THIS PROGRAM READS FORM UNIT 5, WRITES THEMERISTER AVERAGES
C       TO UNIT 7, AND TO UNIT 8, MEAN'S TO UNIT 6
C
        DIMENSION EAN(16)
        INTEGER TELM(160)
        REAL CMIRP(8)/31.,63.,95.,127.,159.,191.,223.,255./
        LOGICAL*1 LFMT(1) /'*'/
C
        DO 20 JWDG=1,16
        TD=0.0
        SUM=0.0
        READ(5,900) TELM
900     FORMAT(20I4)
        DO 10 I=1,160
        SUM=SUM+TELM(I)
10      CONTINUE
        EAN(JWDG)=SUM/160.
         DO 11 K=1,160
         TD=TD+(TELM(K)-EAN(JWDG))**2
11       CONTINUE
         STD=SQRT(TD/159.)
C         OUTPUT CALIBRATION WEDGES MEANS AND STD DEVIATIONS
        WRITE(6,225) JWDG,EAN(JWDG),STD
225     FORMAT(1H-,5X,'WEDGE NUMBER',I3,4X,'MEAN',F7.2,
       1  4X,'STD DEVIATION',F7.2)
20      CONTINUE
C
C       DUMP THEMISTER AVERAGES AND SPACE VEIW TO UNIT 9.
C
        EAN(14)=EAN(15)
        WRITE(9,LFMT)(EAN(J),J=10,14)
C
        WRITE (7,901)(CMIRP(I),I=1,8)
        WRITE (7,901)(EAN(I),I=1,8)
        WRITE (8,901)(EAN(I),I=1,8)
        WRITE (8,901)(CMIRP(I),I=1,8)
901     FORMAT(8F6.2)
        STOP
        END
END OF FILE
```

C.4 Subroutine ITERA

```
C       SUBROUTINE ITERA
C
C      SUBROUTINE FOR OETERMINING IF LAT-LON INTERSECTION
C      IS WITHIN EXTENOEO LIMITS OF GRIO, ANO FOR
C      OETERMINING EXACT LOCATION IF IT IS.
C
        SUBROUTINE ITERA(ALONG, SCAN, POSN, MCHK, SBA, SBAA, SEA, SEAA,
      1            XPOSB, XPOSE)
        COMMON /CONSTO/ PIT2, PIB2, SB, XKB
        COMMON /CONSTS/ RTSC, H, ZORP, SRPM, SI, CI
        COMMON /VARI/ RRL
        COMMON /BLOCK/ R, PI, C1, C2, C4, C5
C
        DIMENSION XNR(4), XAV(5)
C
C         ALAT   = LATITUOE OF LAT-LON INTERSECTION
C         ALONG  = LONGITUDE OF LAT-LON INTERSECTION
C         MCHK   = LOCATION PARAMETER
C            MCHK=0  POINT OUTSIOE EXTENDEO LIMITS OF GRIO
C            MCHK=1  POINT INSIOE EXTENOEO LIMITS OF GRIO
C         SBA    = EXTENOEO SCAN TO BEGIN OUTPUT
C         SBAA   = OVEREXTENOEO SCAN TO BEGIN OUTPUT
C                  (FIRST CHECK ONLY)
C         SEA    = EXTENDED SCAN TO END OUTPUT
C         SEAA   = OVEREXTENDED SCAN TO END OUTPUT
C                  (FIRST CHECK ONLY)
C         XPOSLAT = EXTENDED POSITION TO BEGIN OUTPUT
C         XPOSE  = EXTENOEO POSITION TO END OUTPUT
C         SCAN    = SCAN LOCATION OF ITH POINT IN LINE
C         POSN    = POSITION LOCATION OF ITH POINT IN LINE
C
C       APT GEOMETERIC CORRECTION OATA.
        DATA XNR /312.0, 330.0, 166.0, 93.0/
        DATA XAV /4.0, 3.0, 2.0, 1.5, 1.0/
C
        MCHK = 0
        THETA = RRL - ALONG * C1
C       CHANGE IN EARTHS RAOIUS VERY SMALL FACTOR.
C       R=6367.65 +10.738*COS(2.0*SP)
C       H=AA-R
        X1 = SI * SLAT + SIN(THETA - TPL*SP) * (-CI) * CLAT
        X2 = COS(THETA - TPL*SP) * CLAT
        SNT = ATAN2(X1,X2)
        IF (SNT .LT. 0.0 .ANO. SP .GT. PIB2) SNT = SNT + PIT2
        IF (SNT .GE. SBAA .ANO. SNT .LE. SEAA) GO TO 10
        SP = SNT
        RETURN
C
C
C       ITERATE TO FINO SATELLITE PATH LENGHT
C       FROM EQUATOR
     10 DO 20 J = 1, 10
          ST = THETA - TPL * SNT
          CT = COS(ST)
          ST = SIN(ST)
          CSNT = COS(SNT)
          SSNT = SIN(SNT)
          X1 = CLAT * (SSNT*CT + CI*CSNT*ST) - SI * SLAT * CSNT
          X2 = CLAT * ((1.0 - TPL*CI)*CSNT*CT + (TPL - CI)*SSNT*ST) + SI *
```

```
     1   SLAT * SSNT
        SP = SNT - X1 / X2
C
C     SIN(EARTH ARC LENGHT FROM SUBPOINT)
        ST = SIN(THETA - TPL*SP) * SI * CLAT + CI * SLAT
C     CHECK TO SEE IF NADIR ANG. > FALSE HORISON
        IF (ABS(ST) .GT. SGH) RETURN
        IF (ABS(SNT - SP) .LT. 1E-6) GO TO 40
        SNT = SP
   20 CONTINUE
      WRITE (6,30) ALAT, ALONG
   30 FORMAT (1H , '***** ERROR   NO CONVERGENCE TO POINT AT', ' LATITUD
     1E', F7.1, 2X, 'AND LONGITUDE', F7.1, 2X, 'DEGREES *****')
      RETURN
C
   40 IF (SNT .LT. SBA .OR. SNT .GT. SEA) RETURN
C     CALC SENSOR NADIR ANGLE (FORM SUBPOINT)
C     ANGLE AT EARTH'S CENTER
      X3 = R * ST
      X4 = H + R * (1. - SQRT(1.0 - ST*ST))
      Y = ATAN(X3/X4)
C
C     TIROS-N : DATA POSN.ALONG AVHRR SCAN.  39936HZ @ 6SCANS/SEC
C       FIND (4160HZ) APT POSN. FROM AVERAGED AVHRR DATA
C       CONVERT TO 3200HZ DIGITIZE RATE (USING C5), CENTER=350,
C       RESTRICT  0 < IPOS < 700 =(2*ZDRP).
C
      Y = C4 * ABS(Y)
      IF (Y .GT. 1025.0) RETURN
      SNT = 0.0
      DO 50 J = 1, 4
        SGN = XNR(J)
        IF (Y .LT. SGN) GO TO 60
        SNT = SNT + SGN / XAV(J)
        Y = Y - SGN
   50 CONTINUE
      J = 5
   60 Y = SNT + Y / XAV(J)
      IF (ST .LT. 0.0) Y = -Y
C
C     TIROS-N : CALC POSN. FOR DIGITIZING FREQ.
C
      SCAN = (SP - SB) * RTSC + 1.
      POSN = Y * C5 + ZDRP - XKB
      IF (POSN .LT. XPOSB .OR. POSN .GT. XPOSE) RETURN
      MCHK = 1
      RETURN
C
      ENTRY EQNS(REG)
C     HORIZON ANGLE
      TPL = REG / 360.0
C     SIN(HORISON EARTH ARC)
      SGH = SIN(C1*15.0)
      C4 = 39936.0 / (12.0 * PI)
      C5 = 3200.0 / 4160.0
      AA = R + H
      RETURN
C     CHANGE GEODETIC LATITUDE TO GEOCENTRIC
      ENTRY ITERL(ALAT)
      SP = C1 * ALAT
      TANSP = TAN(SP)
      TEM = 1.0 + 43.02466 / AA
      IF (ALAT .LT. 90.0) SP = ATAN(TANSP/TEM)
      CLAT = COS(SP)
      SLAT = SIN(SP)
      R = 6367.65 + 10.738 * COS(2.*SP)
      H = AA - R
      RETURN
      END
END OF FILE
```

C.5 Subroutine SMOO

```
C      SMOOTHING SUBROUTINE
C
C      SUBROUTINE TO SMOOTH AND ELIMINATE NOISE FROM DATA FIELD.
C
       SUBROUTINE SMOO(MAXSC,IPOS)
C
       LOGICAL*1 LFMT(1)/'*'/
       REAL SMT(10),CORR(301,400) ,RESIO(400), STEMP(301,400), BS(30)
C
       COMMON/TFIELO/TEMP(301,400)
C
C          MAXSC = NUMBER OF COLUMNS IN DATA FIELO
C          IPOS  = NUMBER OF ROWS IN DATA FIELO
C          TEMP(I,J) = OATA VALUE AT EACH POINT (I,J)
C
C    INPUT DATA
C
C         NSMT   = NUMBER OF SMOOTHING OPERATIONS TO BE CARRIED
C                  OUT ON GRIO FIELO BEFORE OUTPUT
C         SMT(I)= SMOOTHING PARAMETER FOR EACH OPERATION
C
       REAO(5,LFMT) NSMT,(SMT(I),I=1,NSMT)
C
       WRITE(6,520)
   520 FORMAT(1H-,14X,'SMOOTHING PARAMETERS')
C
C      BEGIN SMOOTHING LOOP
C
       OO 100 KK=1,NSMT
       SM=SMT(KK)+1.
       SMT4=SMT(KK)/4.
       SMT3=SMT(KK)/3.
       SMT2=SMT(KK)/2.
       IPOSM=IPOS-1
       MXSCM=MAXSC-1
C
C        TWO POINT SMOOTHING IS USED AT CORNERS OF GRIO
C
       CORR(1,1)=SMT2*(TEMP(2,1)+TEMP(1,2))
       CORR(1,MAXSC)=SMT2*(TEMP(2,MAXSC)+TEMP(1,MXSCM))
       CORR(IPOS,1)=SMT2*(TEMP(IPOSM,1)+TEMP(IPOS,2))
       CORR(IPOS,MAXSC)=SMT2*(TEMP(IPOSM,MAXSC)+TEMP(IPOS,MXSCM))
C
C        THREE POINT SMOOTHING IS USED ON SIDES OF GRIO
C
       DO 30 J=2,MXSCM
       CORR(1,J)=SMT3*(TEMP(1,J-1)+TEMP(2,J)+TEMP(1,J+1))
       CORR(IPOS,J)=SMT3*(TEMP(IPOS,J-1)+TEMP(IPOSM,J)+TEMP(IPOS,J+1))
    30 CONTINUE
       OO 40 I=2,IPOSM
       CORR(I,1)=SMT3*(TEMP(I+1,1)+TEMP(I,2)+TEMP(I-1,1))
       CORR(I,MAXSC)=SMT3*(TEMP(I+1,MAXSC)+TEMP(I,MXSCM)+TEMP(I-1,MAXSC))
    40 CONTINUE
C
C        FOUR POINT SMOOTHING IS USED IN INTERIOR OF GRID
C
       OO 50 J=2,MXSCM
       DO 50 I=2,IPOSM
       CORR(I,J)=SMT4*(TEMP(I+1,J)+TEMP(I,J+1)+TEMP(I-1,J)+TEMP(I,J-1))
```

```
      50 CONTINUE
C
C      SMOOTHING CORRECTION IS APPLIED TO EACH GRID POINT
C     AND THE DIFFERENCES BETWEEN ORIGINAL AND SMOOTHED
C     TEMPERATURE FIELDS IS FOUND
C
      KOUNT=0
      S=0.0
      DO 75 J=1,MAXSC
      SUM=0.0
      DO 70 I=1,IPOS
      STEMP(I,J)=(TEMP(I,J)+CORR(I,J))/SM
      DT=ABS(TEMP(I,J)-STEMP(I,J))
      SUM=SUM+DT
   70 CONTINUE
C     RESID IS THE MEAN DIFFERENCE BETWEEN FIELDS.
C
      RESID(J)=SUM/IPOS
      S=S+RESID(J)
 75   CONTINUE
C
C
C     COMPUTE THE MEAN AND STD DEV. OF SMOOTH VS. ORIGINAL FIELDS
C     IN ORDER TO DISTINGUISH NOISE, AND OBSERVE THE EFFECTS
C     OF SMOOTHING.
      SSQ=0.0
      AVE=S/MAXSC
      DO 77 J=1,MAXSC
      SSQ=SSQ+(RESID(J)-AVE)*(RESID(J)-AVE)
 77   CONTINUE
      STDEV=SQRT(SSQ/(MAXSC-1))
      ERR=AVE+2*STDEV
C
C     FIRST SMOOTHING USED TO ELIMINATE NOISE.
      IF (KK .GT. 1)GO TO 199
         DO 76 J=1,MAXSC
      IF(RESID(J) .LT. ERR) GO TO 399
      KOUNT=KOUNT+1
      BS(KOUNT)=J
         DO 78 II=1,IPOS
 78   TEMP(II,J)=STEMP(II,J-1)
      GO TO 76
 399   DO 79 I=1,IPOS
 79   TEMP(I,J)=STEMP(I,J)
 76      CONTINUE
      GO TO 74
C
 199  DO 99 J=1,MAXSC
      DO 99 I=1,IPOS
 99   TEMP(I,J)=STEMP(I,J)
C
      WRITE(6,521) KK,SMT(KK)
      GO TO 100
C
 74   WRITE(6,521) KK,SMT(KK)
  521 FORMAT(1H0,4X,'SMOOTHING OPERATION NUMBER',I3,5X,
     1 'SMOOTHING PARAMETER =',F6.2)
C
      WRITE(6,522) AVE,STDEV
      WRITE(6.525) MAXSC
      WRITE(6,524) KOUNT
      IF(KOUNT .GT. 0) WRITE(6,526) (BS(J),J=1,KOUNT)
 522  FORMAT(1H0,4X,'MEAN OF FIELD DIFFERENCES  =',F8.3,
     1 //,5X,'STANDARD DEVIATION',9X,'=',F8.3)
 523  FORMAT(/,50(10F6.2,/))
 524  FORMAT(1H0,4X,'SCAN LINES REJECTED DUE TO SYNCH PROBLEM =',I4)
 525  FORMAT(1H0,4X,'NUMBER OF SCANS IN WINDOW =',I8)
 526   FORMAT(1H0,4X,'SCAN LINES REJECTED =',5X,10(3F6.0,/,31X))
  100 CONTINUE
      RETURN
      END
END OF FILE
```

C.6 Subroutine CALI

```
C      CALIBRATION SUBROUTINE
C
       SUBROUTINE CALI(MAXSC, IPOS,*,*)
C
C
C      THIS SUBROUTINE IS USEO TO CALIBRATE THE INFRAREO OATA
C      OBTAINEO FROM TIROS-N.  THE ONBOARO COMPUTER IS CALLEO
C      A MANIPULATION INFORMATION PROCESSOR OR MIRP FOR SHORT.
C      A DIGITAL COUNT FROM MIRP IS WHAT IS CONVERTEO TO AN
C      ANALOG SIGNAL ANO TRANSMITTED TO APT STATIONS.  THE
C      PROBLEM INVOLVEO IN CALIBRATING THE INFRAREO OATA IS
C      OETERMINING THE RELATIONSHIP BETWEEN THE U OF A DIGITAL
C      COUNT ANO THE MIRP OIGITAL COUNT.
C
C
       LOGICAL*1 LFMT(1) /'*'/
       REAL T(80), CA(80), CMR(80)
C
       COMMON /TFIELO/ TEMP(301,400)
       COMMON /CALIB/ COF(11)
C
C          MAXSC = NUMBER OF COLUMNS IN DATA FIELO
C          IPOS  = NUMBER OF ROWS IN OATA FIELO
C          RETURN1 = CALIBRATION PROGRAM SUCCEEDS
C          RETURN2 = CALIBRATION PROGRAM FAILS
C          TEMP(I,J) = DATA VALUE AT EACH POINT (I,J)
C
C   INPUT DATA
       NCAL = 36
       BP = 0.0
       REAL IN
C
C        NCAL   = NUMBER OF CALIBRATION LEVELS USEO
C        CA(I),T(I) = DATA VALUES ANO CORRESPONOING TEMPERATURE
C                     VALUES FOR EACH CALIBRATION LEVEL (IN PAIRS)
C
C      OETERMINE RELATION BETWEEN UOFA OIGITAL VALUE ANO BB. TEMP.
C
C      THE FIRST 3 VALUES IN COF ARE THE COEFFICIENTS FITTING THE
C      U OF A WEDGE LEVELS TO THE MIRP WEOGE LEVELS.  THE SECONO 3
C      VALUES ARE COEFFICIENTS FITTING MIRP VALUES TO U OF A VALUES.
C      THE LAST 5 VALUES IN COF(11) ARE B. B. THEMISTER
C      AVERAGES ANO SPACE VIEW.
C
C      USE QUAORATIC FIT TO GET MIRP COUNT CORRESPONOING
C      TO THE RECOROEO VALUES IN COF(7 THRU 11).
C
       DO 10 J = 7, 11
         COF(J) = COF(1) + COF(2) * COF(J) + COF(3) * COF(J) ** 2
C
C
C      CONVERT FROM 8 TO 10 BIT NUMBER
         COF(J) = 4 * COF(J)
    10 CONTINUE
C
C      CONVERT COF(J) TO TEMPERATURE
C      COEFFICIENTS OBTIANEO BEFORE SATELLITE IS LAUNCHEO.
       T1 = 277.73 + 0.047752 * COF(7) + 8.29E-6 * COF(7) ** 2
       T2 = 277.41 + 0.046637 * COF(8) + 11.01E-6 * COF(8) ** 2
       T3 = 277.14 + 0.045188 * COF(9) + 14.77E-6 * COF(9) ** 2
```

```
      T4 = 277.42 + 0.046387 * COF(10) + 10.59E-6 * COF(10) ** 2
C
C     TAKE AVERAGE OF PRT TEMP'S
C     TBB IS THE ACTUAL TEMPERATURE OF THE RADIOMETER HOUSING.
C
      TBB = (T1 + T2 + T3 + T4) / 4.
C
      CALL PLANCK(TBB, QN)
C
C     TO ACCOUNT FOR NON-LINEARITIES
C     ASSUME THE RAOIANCE OF SPACE=-1.151,  CMSP=250
C
      SP = -1.151
      CMSP = 250.
C     FROM N=G*CM+IN
      G = (SP - QN) / (CMSP - COF(11)/4.)
      IN = SP - G * CMSP
C
C     NOW WORK BACKWAROS- FIND N FOR EVERY 3'INTERVAL FROM -70' TO 30'C
C
      J = 0
      OO 20 K = 200, 305, 3
        J = J + 1
        T(J) = K
        CALL PLANCK(T(J), QN)
        CMR(J) = (QN - IN) / G
C
C     INTERPOLATE TO GET U OF A COUNT FROM MIRP COUNT
C
        CA(J) = COF(4) + COF(5) * CMR(J) + COF(6) * CMR(J) ** 2
   20 CONTINUE
C
      WRITE (6,30) (CA(I),T(I),I=1,NCAL,5)
   30 FORMAT (1H-, 14X, 'CALIBRATION PARAMETERS', //, 5X, 'CALIBRATION C
     1URVE :', 5X, 'OATA LEVELS', 5X, 'TEMPERATURES (IN OEG K)', //,
     2       70(31X,F8.2,14X,F7.2,/))
C
C
C       CALIBRATE EACH GRID POINT
C
      DO 70 J = 1, MAXSC
        OO 70 I = 1, IPOS
C      SET VALUES OUTSIDE OF TEMP RANGE TO EXTREME VALUES
          IF (TEMP(I,J) .LE. CA(1) .OR. TEMP(I,J) .GE. CA(NCAL))
     1        GO TO 40
          BP = BP + 1
          IF (TEMP(I,J) .GT. CA(1)) TEMP(I,J) = CA(1)
          IF (TEMP(I,J) .LT. CA(NCAL)) TEMP(I,J) = CA(NCAL)
          TEMP(I,J) = TEMP(I,J) - 273.15
          GO TO 70
   40     OO 50 K = 1, 35
            IF (TEMP(I,J) .LT. CA(K) .ANO. TEMP(I,J) .GE. CA(K + 1))
     1          GO TO 60
   50     CONTINUE
C
C     PERFORM LINEAR INTERPOLATION
C
   60     DUM = (TEMP(I,J) - CA(K + 1)) / (CA(K) - CA(K + 1))
          DUM2 = DUM * (T(K) - T(K + 1)) + T(K)
C
```

```
C     CONVERT TO 'C
           TEMP(I,J) = DUM2 - 273.15
   70 CONTINUE
      WRITE (6,90) BP
      RETURN 1
C
   80 WRITE (6,100)
   90 FORMAT (F20.0, 5X, 'BAD DATA POINTS IN DATA FIELD')
  100 FORMAT (1H0, '***** ERROR   CALIBRATION FAILURE *****')
      RETURN 2
      END
C
C
      SUBROUTINE PLANCK(TEMK, QN)
      DIMENSION PHI(60)
C
C     THIS SECTION DETERMINES THE RADIANCE OF A BLACK BODY
C     WITH TEMPERATURE T IN THE 11MICRON BAND. (ALL CONSTANTS
C     WERE OBTAINED FROM TIROS-N WRITE UP)
C
      DATA PHI /0.0, 0.33701E-4, 0.73654E-4, 0.10611E-3, 0.14390E-3,
     10.24906E-3, 0.50024E-3, 0.95828E-3, 0.15939E-2, 0.23496E-2,
     10.31779E-2, 0.40893E-2, 0.51155E-2, 0.62748E-3, 0.74753E-2,
     20.85702E-2, 0.94211E-2, 0.10012E-1, 0.10418E-1, 0.10718E-1,
     30.10961E-1, 0.11164E-1, 0.11335E-1, 0.11489E-1, 0.11635E-1,
     40.11786E-1, 0.11954E-1, 0.12147E-1, 0.12374E-1, 0.12644E-1,
     50.12877E-1, 0.12887E-1, 0.12539E-1, 0.12331E-1, 0.12071E-1,
     60.11931E-1, 0.11982E-1, 0.12175E-1, 0.12387E-1, 0.12766E-1,
     70.13462E-1, 0.14131E-1, 0.14239E-1, 0.13355E-1, 0.11367E-1,
     80.87492E-2, 0.60630E-2, 0.38563E-2, 0.23495E-2, 0.13991E-2,
     90.84093E-1, 0.51723E-3, 0.33615E-3, 0.24878E-3, 0.20690E-3,
     *0.16664E-3, 0.11659E-3, 0.59942E-4, 0.61584E-8, 0.0/
C
C
C     INITIAL VALUE OF V
C     IS     V=840.0337
C     TO ACCOUNT FOR INCREMENTING
      V = 837.61981
      DV = 2.41389
      QN = 0.0
C
C     CALCULATE PLANK FN.
      DO 20 I = 1, 60
C
        V = V + DV
C
        PLANK = (1.1910659E-5*(V**3)) / (EXP(1.438833*V/TEMK) - 1)
        QN = QN + PLANK * PHI(I) * DV
   20 CONTINUE
C
      RETURN
      END
END OF FILE
```

C.7 Program PLT

```
C     PROGRAM  PLT
C     PROGRAM TO PLOT TEMPERATURE OR REFLECTANCE FIELDS,
C     POST TOWNSITE LOCATIONS, DRAW LAT-LON LINES AND
C     OUTLINE ALBERTA. (PROGRAM COULD BE CONSIDERABLY SHORTER
C     IF I-O OPTIONS WERE RESTRICTED.)
C
C     INPUT - OUTPUT
C        UNIT 5  : PROGRAM PARAMETERS
C        UNIT 9  : PLOT OUTPUT FOR CALCOMPQ PLOTTING
C        UNIT 13 : DATA FIELD
C        UNIT 16 : OUTLINES WITH ORIGIN OF (0,0)
C
C     NCON = NUMBER OF CONTOUR INTERVALS
C            (CONTOUR INTERVALS STORED IN CTR(I))
C     BUP = BLOW-UP FACTOR
C     MTNS = PLOT B.C.- ALBERTA BORDER
C            0 = NO,   1 = YES
C     LCHK1= LAT-LON LINES DESIRED ?
C            0 = NO,   1 = YES
      LOGICAL*1 LFMT(1) /'*'/
      REAL CTR(10)
C
      READ (5,LFMT) NCON, BUP, LCHK1, MTNS
      READ (5,LFMT) (CTR(I),I=1,NCON)
      SCALP = 59.346
      SCALS = 76.737
C
      REAL TFLD(400,301)
      REAL VP(8) /4*0.0, -1.0, 2*0.0, 0.2/
C       IP(4)=0 NO CONTOUR VALUES ARE PLOTTED
C       IP(4)=2 CONTOUR VALUES ARE PLOTTED 3IN. APART
      INTEGER IP(8) /0, 1, 0, 2, 1, 1, 0, 0/
      CALL PLOTS
C
C
      READ (13) IPOS, MAXSC
      DO 10 JJ = 1, MAXSC
   10 READ (13) (TFLD(JJ,II),II=1,IPOS)
C
      READ (16,120) MM
C     CALCULATE SYMBOL AND MAP SIZE.
C      RADAR RANGE RR=.5 INCHES CORRESPONDS TO 80 MILES
C      MAP SCALE IS 1:10E6
      SX = (MAXSC/SCALS) * BUP
      SY = (IPOS/SCALP) * BUP
      RR = 0.50 * BUP
      CHT = 0.05 * BUP
      THT = 0.02 * BUP
C
C
      CALL PLOT(1.0, 1.0, -3)
      CALL CONTUR(SX, SY, TFLD, 400, MAXSC, IPOS, CTR, NCON, IP, VP)
C
   20 READ (16,110) XP, YP
      XP = (XP/SCALS) * BUP
      YP = (YP/SCALP) * BUP
      CALL CIRCL2(XP, YP, 0., 360., RR)
C     POST EDMONTON AND CALGARY
      READ (16,110) XE, YE
```

```
      XE = (XE/SCALS) * BUP
      YE = (YE/SCALP) * BUP
      CALL SYMBOL(XE, YE, CHT, 3, O., -1)
      READ (16,110) XC, YC
      XC = (XC/SCALS) * BUP
      YC = (YC/SCALP) * BUP
      CALL SYMBOL(XC, YC, CHT, 3, O., -1)
C     READ AND POST TOWNSITES IN RADAR RANGE
      DO 30 J = 1, 8
        READ (16,110) XT, YT
        XT = (XT/SCALS) * BUP
        YT = (YT/SCALP) * BUP
        CALL SYMBOL(XT, YT, THT, 3, O., -1)
   30 CONTINUE
      IF (MTNS .EQ. 1) GO TO 40
C     N,S,E,W  LINES ARE DRAWN
      READ (16,110) X, Y
      X = (X/SCALS) * BUP
      Y = (Y/SCALP) * BUP
      CALL PLOT(X, Y, 3)
      READ (16,110) X, Y
      X = (X/SCALS) * BUP
      Y = (Y/SCALP) * BUP
      CALL PLOT(X, Y, 2)
      READ (16,110) X, Y
      X = (X/SCALS) * BUP
      Y = (Y/SCALP) * BUP
      CALL PLOT(X, Y, 3)
      READ (16,110) X, Y
      X = (X/SCALS) * BUP
      Y = (Y/SCALP) * BUP
      CALL PLOT(X, Y, 2)
C
      GO TO 90
C
C     DRAW ROCKIES
   40 MM = MM - 11
      DO 50 I = 1, MM
        READ (16,110,END=60) X, Y
        X = (X/SCALS) * BUP
        Y = (Y/SCALP) * BUP
        IF (I .EQ. 1) CALL PLOT(X, Y, 3)
        IF (I .NE. 1) CALL PLOT(X, Y, 2)
   50 CONTINUE
C
C     ARE LAT LON LINES DESIRED?
   60 IF (LCHK1 .EQ. O) GO TO 90
C     PROGRAM TO PRODUCE LAT LON LINE PLOT.
C
   70 READ (11,100,END=90) J, MZERO, MLL, LLAT
      DO 80 I = 1, J
        READ (11,110) XL, YL
        XL = (XL/SCALS) * BUP
        YL = (YL/SCALP) * BUP
        IF (I .EQ. 1) CALL PLOT(XL, YL, 3)
        IF (I .NE. 1) CALL PLOT(XL, YL, 2)
   80 CONTINUE
      GO TO 70
   90 CALL PLOT(0.0, 0.0, 999)
  100 FORMAT (4I4)
  110 FORMAT (2F7.2)
  120 FORMAT (I4)
  130 FORMAT (34F4.0)
      STOP
      END
END OF FILE
```

C.8 Program GREY

```
C       PROGRAM  GREY
C
C           PROGRAM TO PRODUCE GREY-LEVEL MAP OF DATA FIELD
C           ON THE ESPP.  THIS PROGRAM WORKS IN CONJUNCTION
C           WITH PROGRAM  JHON:GREY
C
        LOGICAL*1 LFMT(1) /'*'/
        LOGICAL*1 LFLD(150,150), P(2)
        DIMENSION YSCAN(3), XPOS(3)
        INTEGER ITRANS(256)
        REAL*4 LINE(78)
        INTEGER*2 NLEV
        EQUIVALENCE(NLEV,P)
        ISIZE=1
C
C       READ IN CITY LOCATIONS
        READ(16,LFMT)(YSCAN(I),XPOS(I),I=1,3)
C
C
C       SET UP TRANSLATION TABLE (ITRANS)
C
1       REWIND 13
        DO 5 J=1,256
        ITRANS(J)=J-1
5       CONTINUE
        IP=-1
C
        READ(5,LFMT,END=100) IR
        KORR=1
        IF(IR.EQ.1) KORR=81
C
20      READ(5,LFMT,END=100) II,IO
        II=II+KORR
        IF(II.LT.1.OR.II.GT.256.OR.IO.LT.O.OR.IO.GT.255)GO TO 95
        IF(IP.LT.O) GO TO 90
        IF(II-IP) 95, 90, 30
30      SLOPE=FLOAT(IO-IOP)/FLOAT(II-IP)
        DO 40 J=IP,II
        ITRANS(J)=IOP+INT(0.5+(J-IP)*SLOPE)
40      CONTINUE
90      IP=II
        IOP=IO
        GO TO 20
95      WRITE(6,999) II,IO,IP,IOP
999     FORMAT(' ***ERROR IN ORDINATE VALUES FOR TRANSLATE TABLE***',
       1   4I4)
        STOP 99
100     IF(IP.LT.O)STOP
C
        READ(13) IPOS,MAXSC
         WRITE(6,99) IPOS,MAXSC
99       FORMAT(2I5)
C
C       CONVERT REAL*4 TO INTERGER*2 THEN TO LOGICAL*1
C
        DO 11 JJ=1,MAXSC
        READ(13) LINE
        II=1
        KOUNT=0
```

```
      DO 11 I=1,IPOS
C
      ILINE=KORR+INT(SIGN(0.5,LINE(I))+LINE(I))
      NLEV =ITRANS(ILINE)
C
      KOUNT=KOUNT+1
C
      IF(KOUNT.NE.4) GO TO 10
      LFLD(II,JJ)=P(2)
      II=II+1
      KOUNT=0
C
   10 LFLD(II,JJ)=P(2)
      II=II+1
   11 CONTINUE
C
C     PLOT CITIES YEG,YQF,YYC
C
      DO 220 ICITY=1,3
      IXPOS=IFIX(XPOS(ICITY)*1.25+.2)
      IYSCAN=IFIX(YSCAN(ICITY)+.5)
      IT1=IXPOS-ISIZE
      IT2=IXPOS+ISIZE
C     BLACK + SYMBOL ON WHITE BACKGROUND & VICE VERSA
      NLEV=0
      P(2)=LFLD(IXPOS,IYSCAN)
      I=0
      IF(NLEV.LT.100) I=235
      NLEV=I
C     STRIPE ALONG SCAN
      DO 200 I=IT1,IT2
  200 LFLD(I,IYSCAN)=P(2)
C     STRIPE ACROSS SCAN
      IT1=IYSCAN-ISIZE
      IT2=IYSCAN+ISIZE
      DO 210 J=IT1,IT2
  210 LFLD(IXPOS,J)=P(2)
  220 CONTINUE
      CALL GREY (LFLD,150,MAXSC,2)
C
      GO TO 1
      END
END OF FILE
```

C.9 Program RAIN

```
C       PROGRAM  RAIN
C
C          ALGORITHM FOR IR & VIS DATA TO DETERMINE RAIN AREAS.
C          DATA IS READ IN UNFORMATTED IS TESTED AND RESULT
C          IS WRITTEN ON UNIT 15.
C
        LOGICAL*1 LFMT(1) /'*'/
C
        COMMON/TFIELD/TEMP(301,400)
        DIMENSION T(200,200),VIS(200,200)
        READ(5,LFMT)T1,V1,T2,V2
C
C
        READ(13) IPOS,MAXSC
        READ(14) JPOS,NAXSC
        IF(IPOS .NE.JPOS .OR. MAXSC .NE. NAXSC) WRITE(6,99)
C
        DO 11 JJ=1,MAXSC
        READ(13) (T(II,JJ),II=1,IPOS)
        READ(14) (VIS(II,JJ),II=1,JPOS)
 11       CONTINUE
C
        DO 10 J=1,MAXSC
        DO 10 I=1,IPOS
C
C       DATA TESTS
        IF(T(I,J).GT. T1 .OR. VIS(I,J).LT.V1) GO TO 8
        TEMP(I,J)=51.
        IF(T(I,J).LE. T2 .AND. VIS(I,J).GT.V2) TEMP(I,J)=85.
        GO TO 10
C
 8      TEMP(I,J)=0.
 10     CONTINUE
C       SMOOTH FIELD
        CALL SMOO(MAXSC,IPOS)
C
        WRITE(15) IPOS,MAXSC
        DO 12 J=1,MAXSC
 12     WRITE(15)(TEMP(I,J),I=1,IPOS)
 99     FORMAT('INPUT FILES NOT FROM SAME PASS.')
        WRITE(6,LFMT)IPOS,MAXSC,JPOS,NAXSC
        STOP
        END
END OF FILE
```

Appendix D

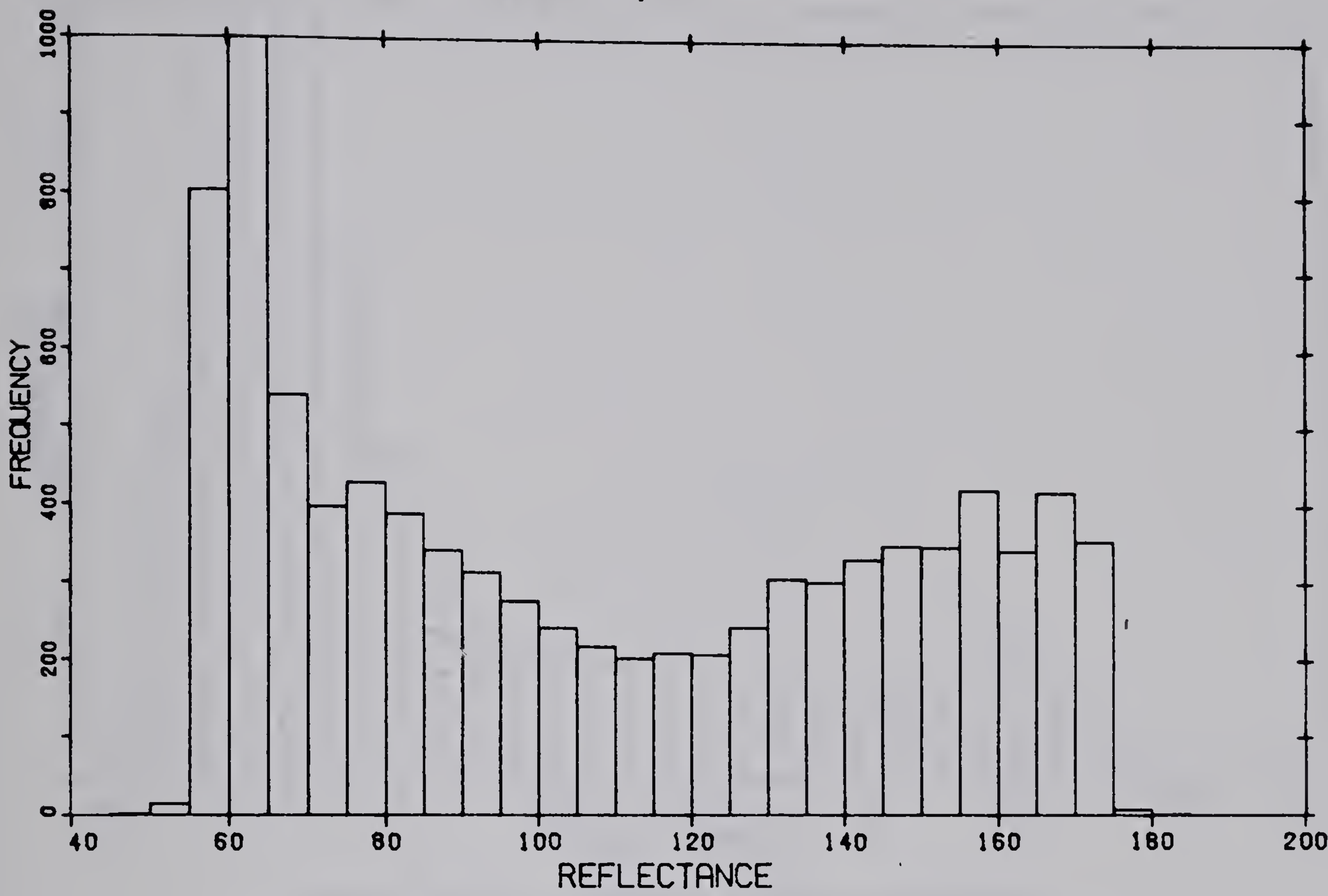
D.1 Program FREQ

```
C      PROGRAM  FREQ
C
C         PROGRAM TO DETERMINE THE FREQUENCY OF DIGITAL
C         COUNTS IN GROUPS (EVERY 5 COUNTS).
C         DATA READ IN UNFORMATTED IS TESTED AND COMBINED
C         FREQUINCIES ARE OUTPUT ALONG WITH
C         BOTH IR & VIS FREQUINCIES
C
       LOGICAL*1 LFMT(1) /'*'/
       LOGICAL*4  DASH/ZBFBFBFBF/, CNR/ZABABABAB/, VLIN/'|'/
C
       DIMENSION T(200,200),VIS(200,200),DT(22)
       INTEGER IBOTH(40,40),ICT(40)/40*0/,ICV(40)/40*0/
       REAL BOTH(40,40)
C
       DO 5 I=1,40
       DO 5 J=1,40
       BOTH(I,J)=0.0
5      IBOTH(I,J)=0
C
       WRITE(5,988)
988      FORMAT('PLEASE ENTER PASS NUMBER')
       READ(5,987)IPASS
987     FORMAT(I4)
       READ(13) IPOS,MAXSC
       READ(14) JPOS,NAXSC
       IF(IPOS .NE.JPOS .OR. MAXSC .NE. NAXSC) WRITE(6,99)
       GRID=IPOS*MAXSC
       AREA=GRID*3.655
C
       DO 11 JJ=1,MAXSC
       READ(13) (T(II,JJ),II=1,IPOS)
       READ(14) (VIS(II,JJ),II=1,JPOS)
11     CONTINUE
C
       DO 10 J=1,MAXSC
       DO 10 I=1,IPOS
C
C      FREQUENCY TABLE CHECK
C         IT=1 COLDER THAN -70
C         IT=2  -65.1 TO -70.0 ETC.
C         IT=20 WARMER THAN +20 CELCIUS
C
C
       IT=IFIX((T(I,J)+80.0)/5.)
       IT=MAXO(1,IT)
       IT=MINO(20,IT)
C
       ICT(IT)=ICT(IT)+1
C
       IV=IFIX(VIS(I,J)/5.)
       IV=MAXO(8,IV)
       IV=MINO(38,IV)
C
       ICV(IV)=ICV(IV)+1
C
       IBOTH(IT,IV)=IBOTH(IT,IV)+1
C
C
C       SCALE LARGE COUNTS FOR PLOTTING
```

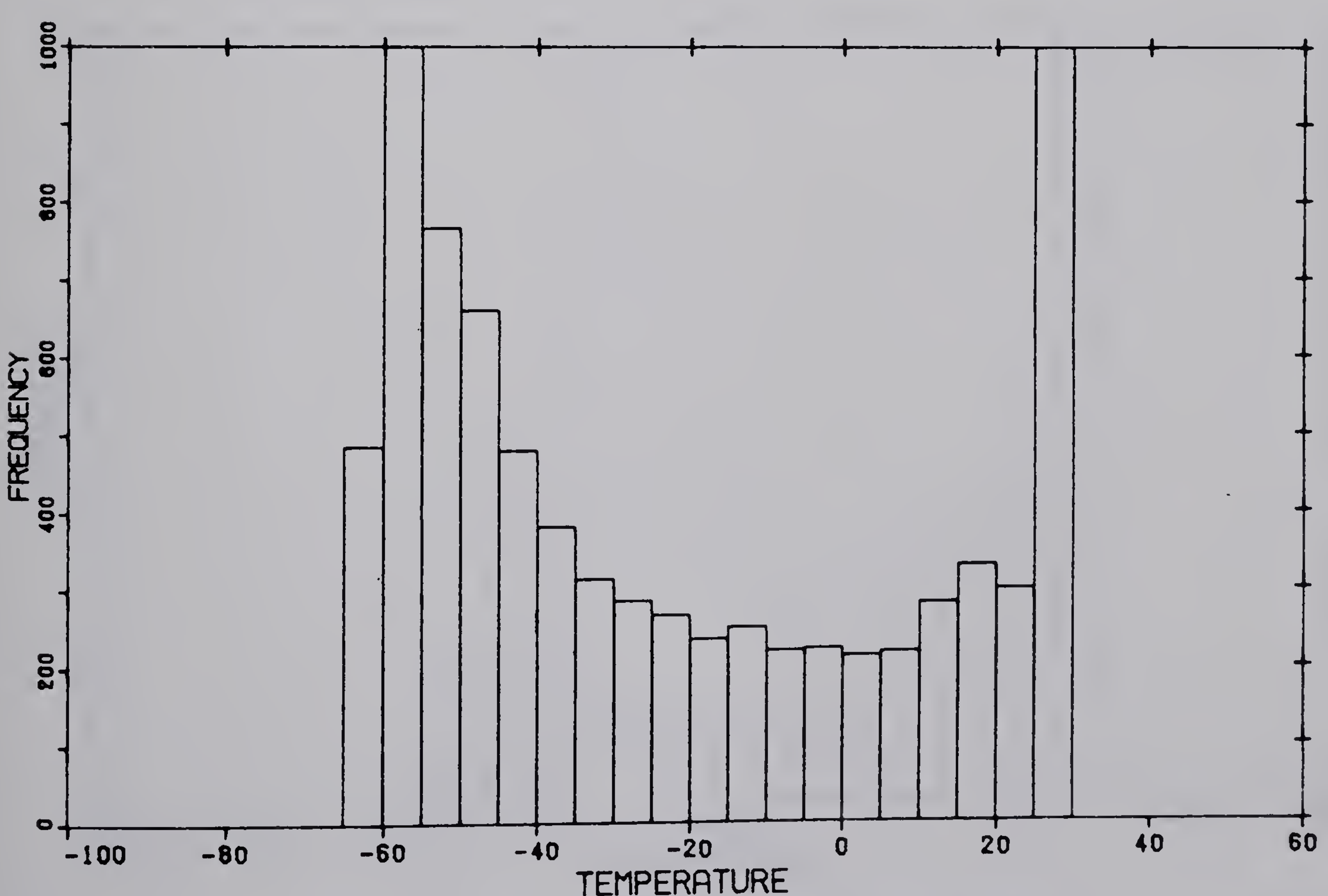
```
      IF(ICT(IT).GT.1000)ICT(IT)=999
      IF(ICV(IT).GT.1000)ICV(IT)=999
C
      IF(IT.GT.15.OR.IV.LT.14)GO TO 10
      CLDA=CLDA+1.
C
 10   CONTINUE
C
      DO 16 IV=8,38
      DO 16 IT=1,20
      BOTH(IT,IV)=100.*IBOTH(IT,IV)/CLDA
      IF(BOTH(IT,IV) .LT. 0.1) BOTH(IT,IV) = 0.0
 16   CONTINUE
      PCNT=100.*CLDA/GRID
      K=-75
C     K=80 FOR EXTENDED RANGE
      DO 13 J=1,22
      K=K+5
 13   DT(J)=K
C
C
      WRITE(6,989) IPASS,PCNT,AREA
 989  FORMAT(1H1,46X,'FREQUENCY TABLE FOR ORBIT NUMBER',2X,I4,/,
     1   14X,36X,'Y AXIS = VISIBLE REFLECTANCE',/,
     1   14X,36X,'X AXIS = INFARED TEMPERATURES',/,
     1   14X,30X,'VALUES GIVEN IN PERCENT OF TOTAL CLOUD COVER',/,
     1   42X,F4.1,'% CLOUD COVER OVER',2X,F7.0,1X,'SQUARE KILOMETERS',/)
C
C     THE LIMITS OF SEVERAL VARIABLES HAVE BEEN CHANGED FOR OUTPUT
C     THESE ARE IO=200,IV=39-K,IT=1,16,K=1,25
C     WRITE OUT COMBINED FREQ
      IO=185
      DO 12 K=1,22
      IO=IO-5
      IV=36-K
C     SUPPRESS ZEROS
      CALL FTNCMD('SET ZEROSUPPRESS=ON;')
C
      WRITE(6,999) IO ,VLIN, VLIN, (BOTH(IT,IV),IT=2,16)
 12   CONTINUE
 999  FORMAT(1H ,I5,A1,/,6X,A1,16F7.1)
      CALL FTNCMD('SET ZEROSUPPRESS=OFF;')
      ISVTY=70
      WRITE(6,990) ISVTY,CNR,(DASH,I=1,28)
 990   FORMAT(1H ,3X,I2,A1,29A4)
      WRITE(6,991) (DT(I),I=1,17)
 991  FORMAT(6X,F5.0,17(F7.0))
C
C
      WRITE(3,994) IPASS
 994  FORMAT(3X,'ORBIT',I5,2X,'INFRARED DATA HISTOGRAM',13X,
     1    'TEMPERATURE',7X,'FREQUENCY')
      DO 14 K=1,21
      WRITE(3,LFMT)  DT(K+1),ICT(K)
 14   CONTINUE
      WRITE(3,993) IPASS
 993  FORMAT(3X,'ORBIT',I5,2X,'VISIBLE DATA HISTOGRAM',13X,
     1   'REFLECTANCE',8X,'FREQUENCY')
      IO=200
      DO 15 K=1,31
      IO=IO-5
      J=39-K
      WRITE(3,LFMT) IO,ICV(J)
 15   CONTINUE
      STOP
 99   FORMAT('DISLEXIC ?  INPUT FILES NOT FROM SAME PASS')
      WRITE(6,LFMT)IPOS,MAXSC,JPOS,NAXSC
      STOP
      END
END OF FILE
```

D.2 Frequency Histograms

D.2.1 Case study #1 TIROS-N Orbit 3758

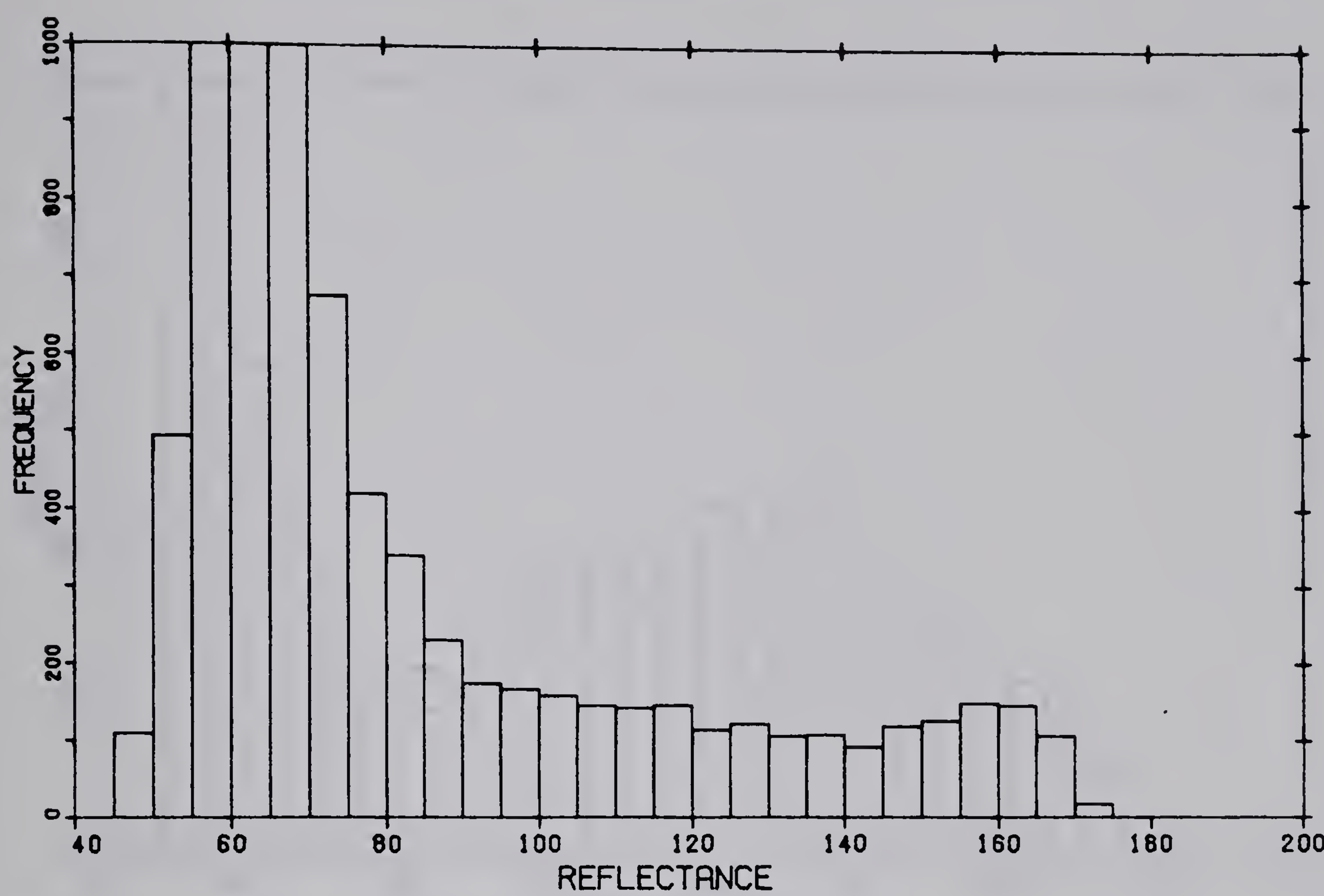


ORBIT 3758 VISIBLE DATA HISTOGRAM

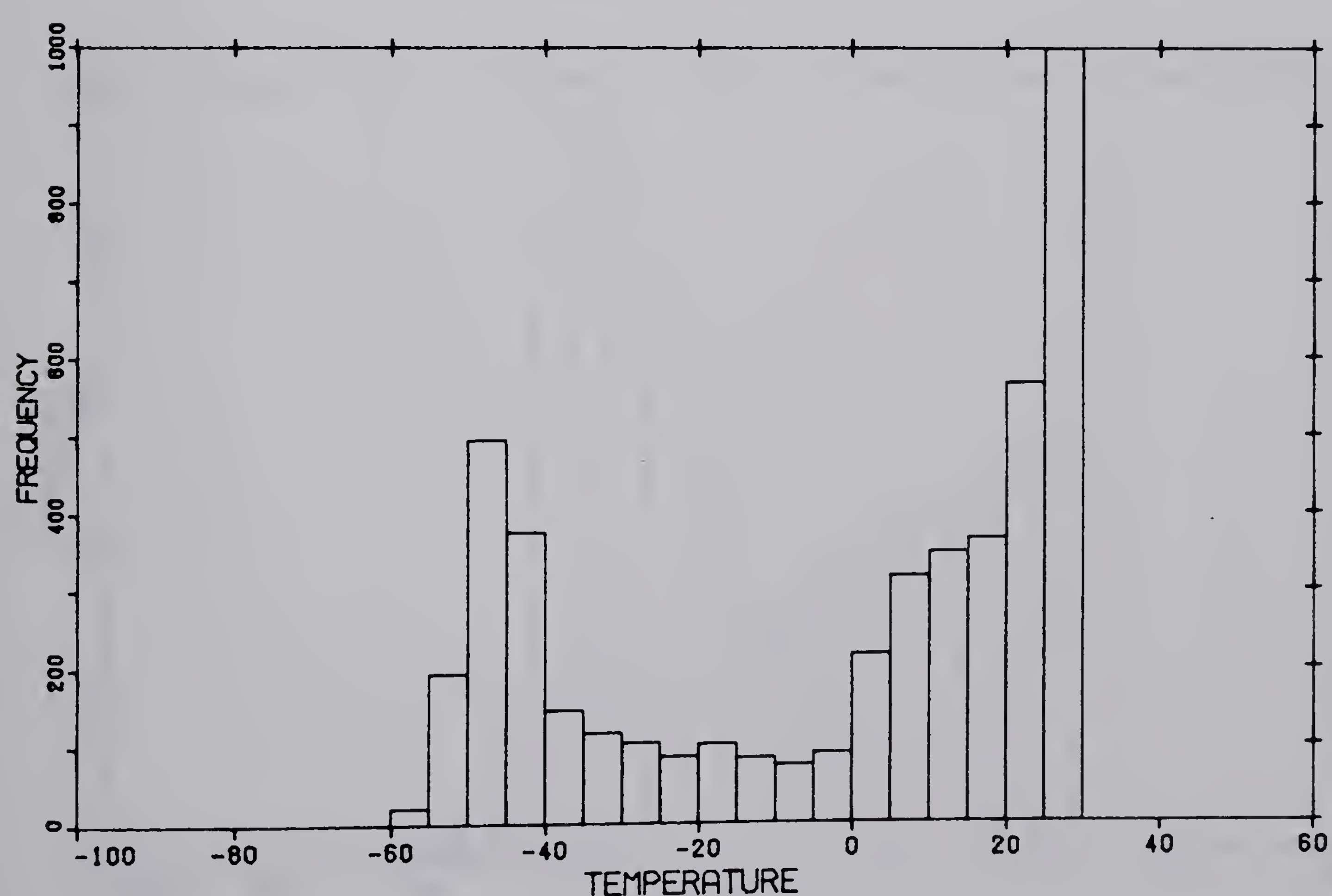


ORBIT 3758 INFRARED DATA HISTOGRAM

D.2.2 Case study #2 TIROS-N Orbit 3772

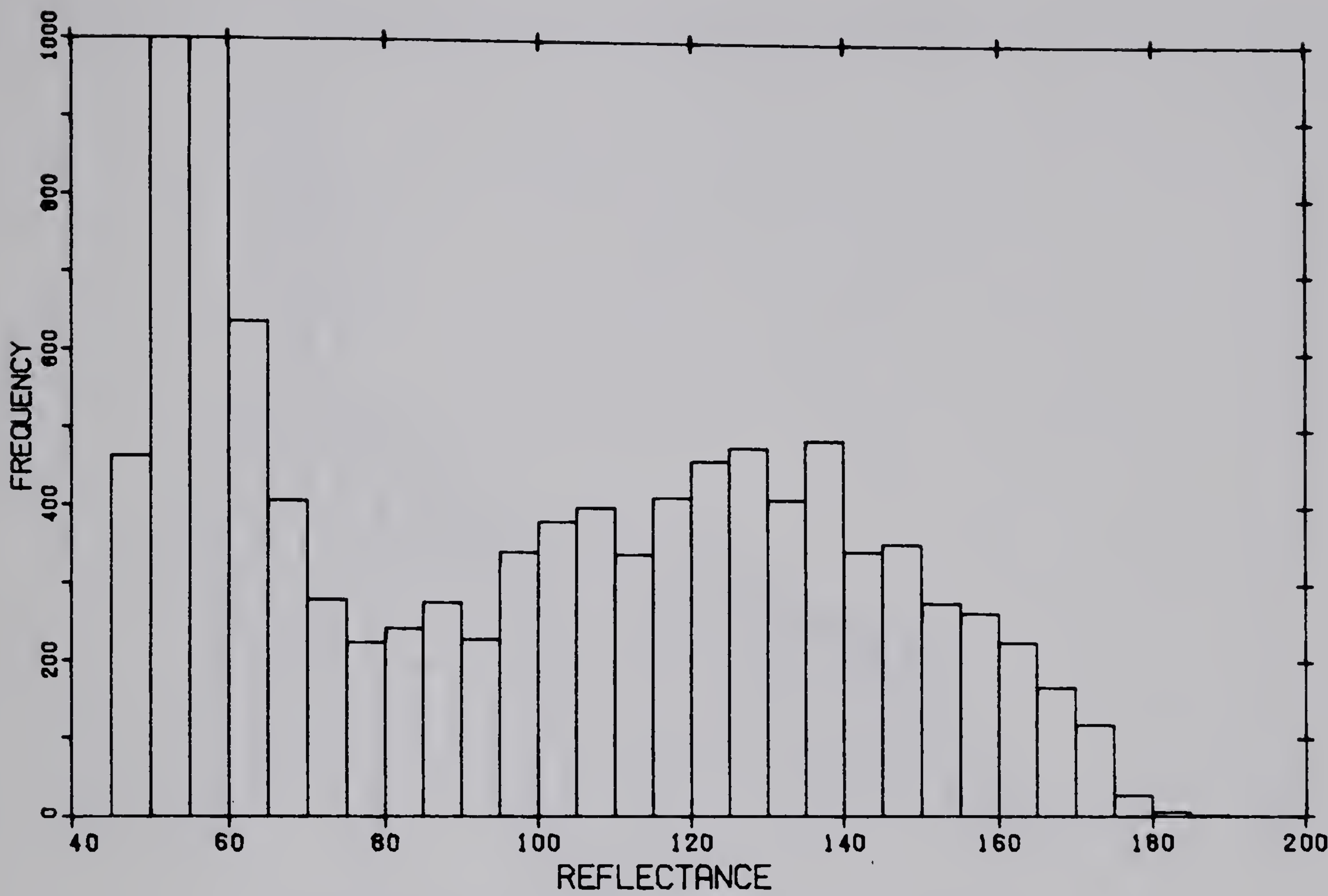


ORBIT 3772 VISIBLE DATA HISTOGRAM

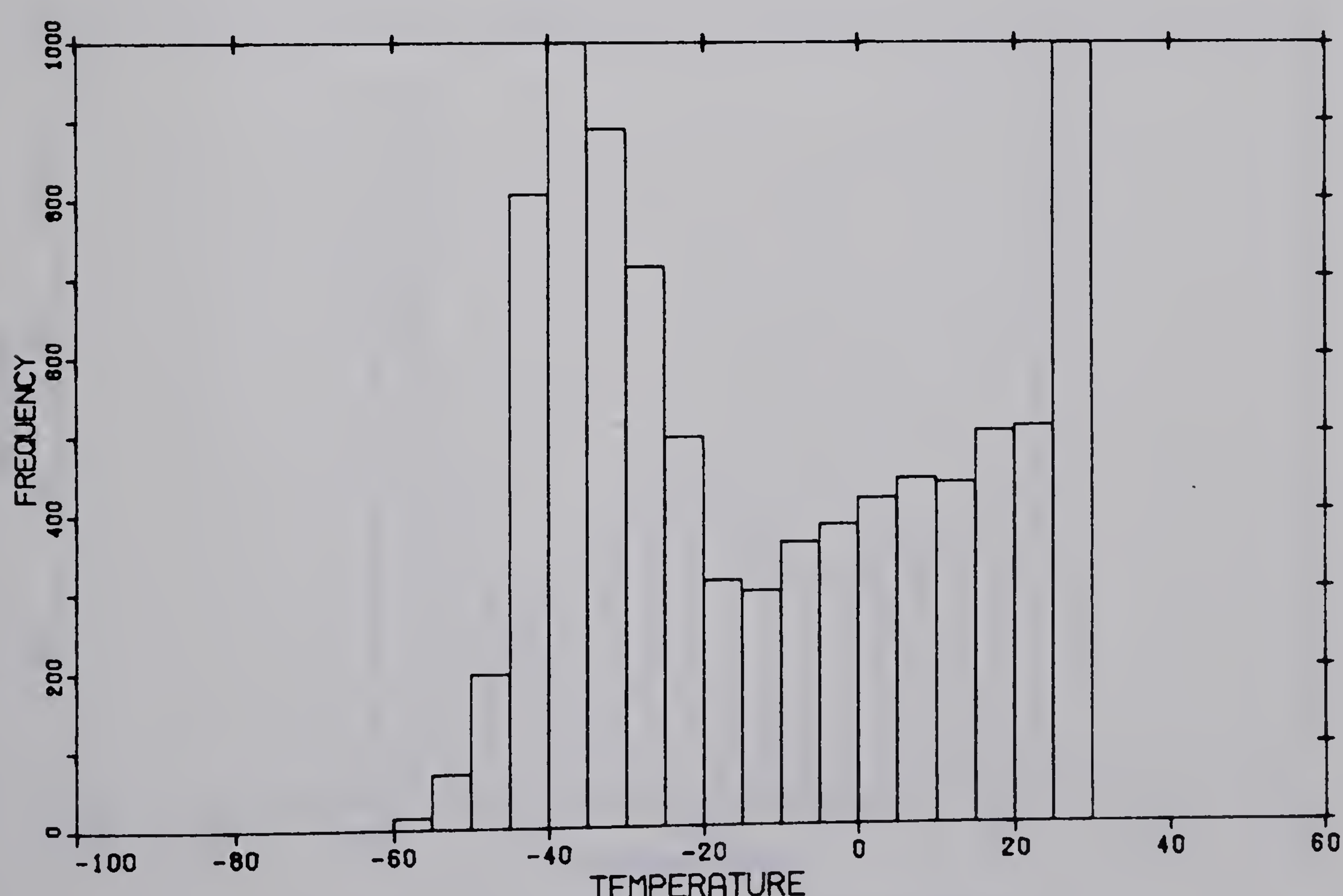


ORBIT 3772 INFRARED DATA HISTOGRAM

D.2.3 Case study #3 TIROS-N Orbit 3814

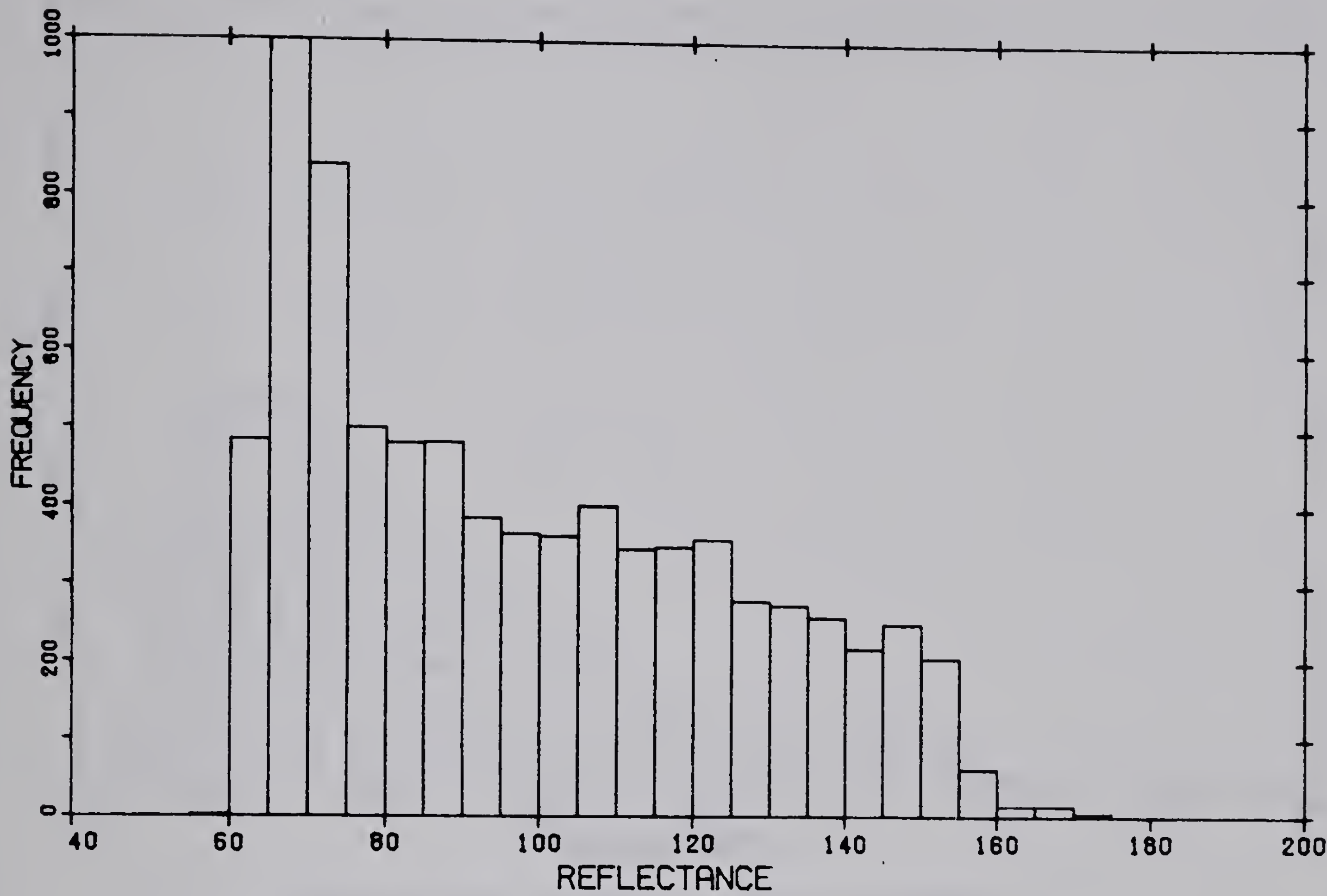


ORBIT 3814 VISIBLE DATA HISTOGRAM

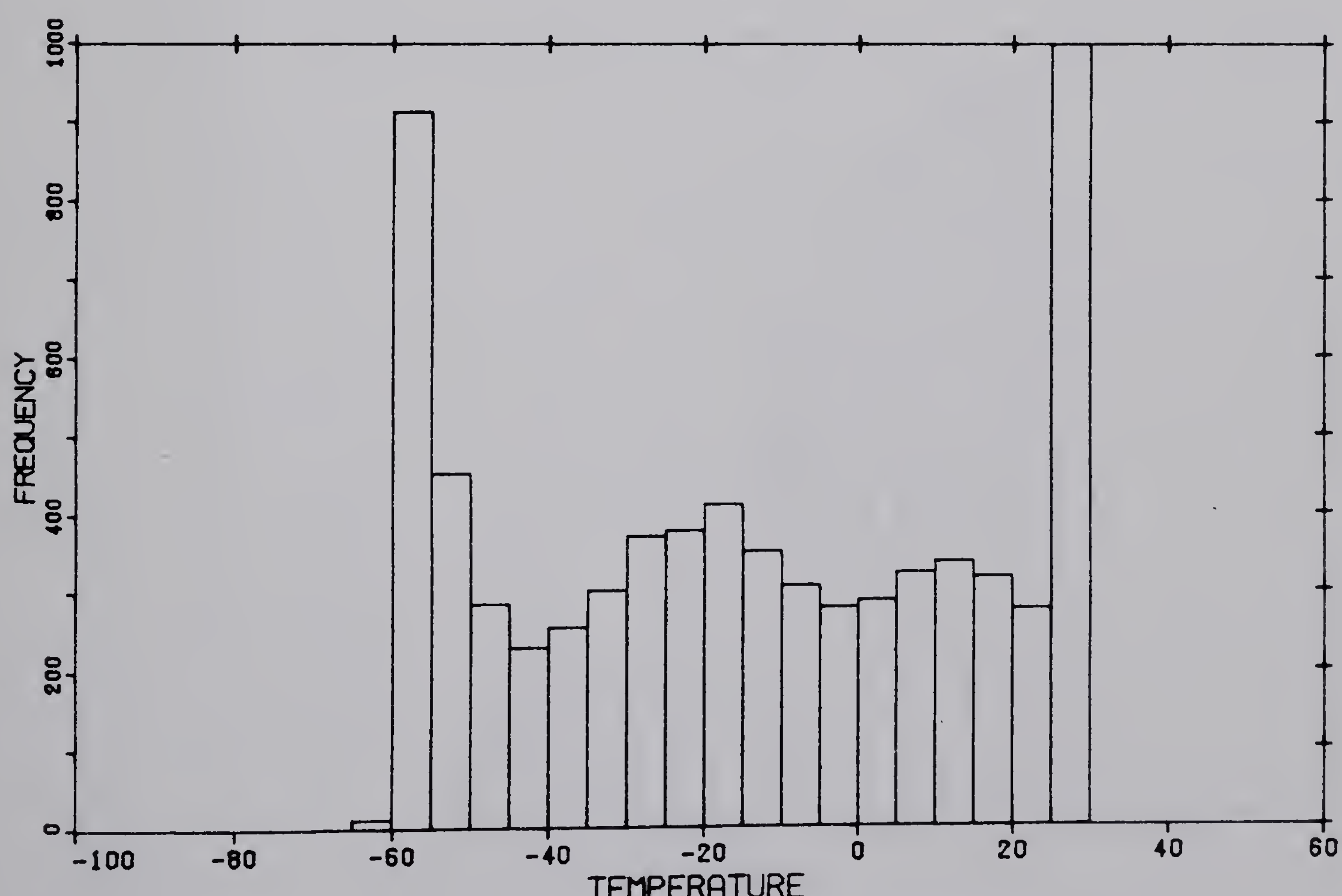


ORBIT 3814 INFRARED DATA HISTOGRAM

D.2.4 Case study #4 TIROS-N Orbit 3970

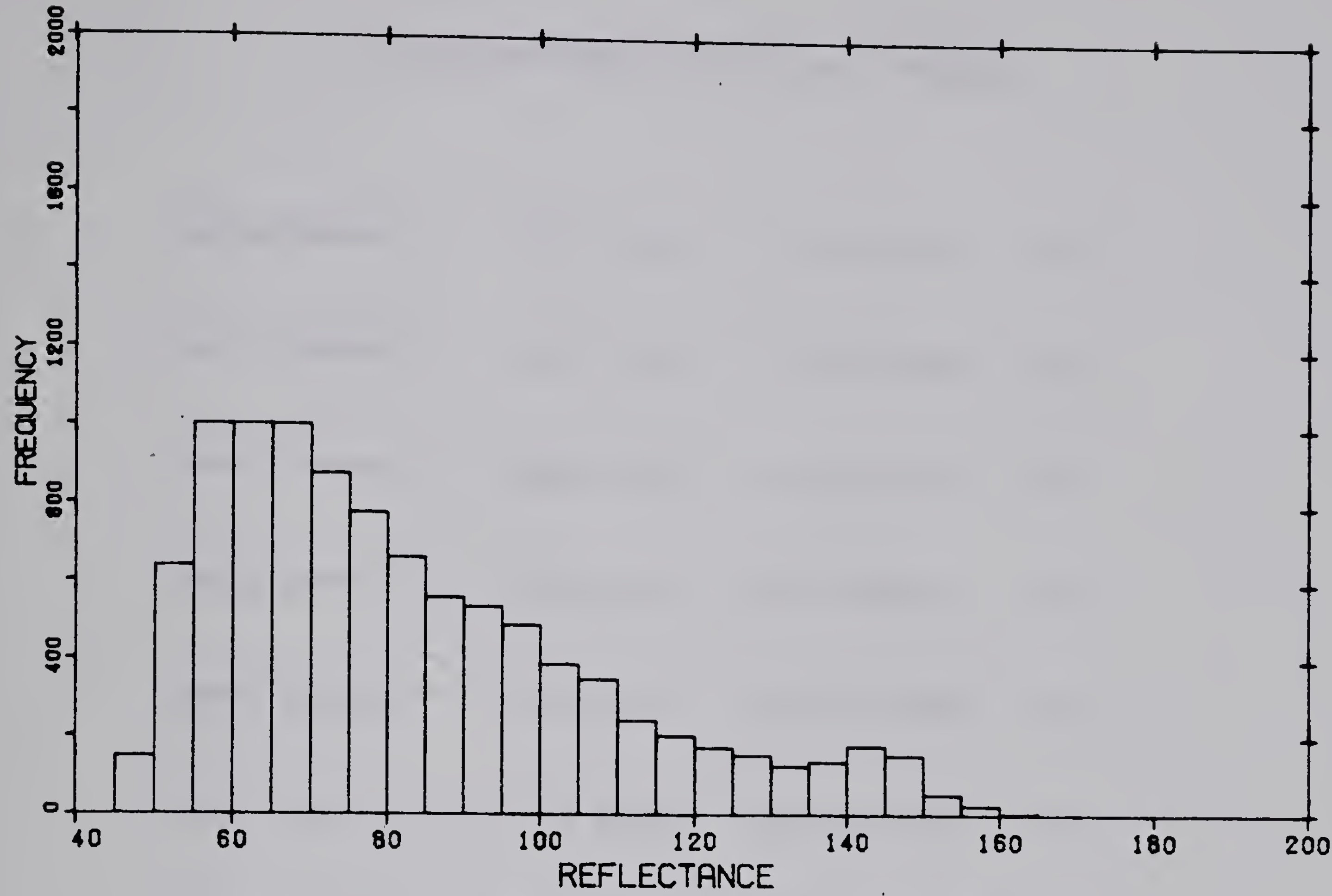


ORBIT 3970 VISIBLE DATA HISTOGRAM

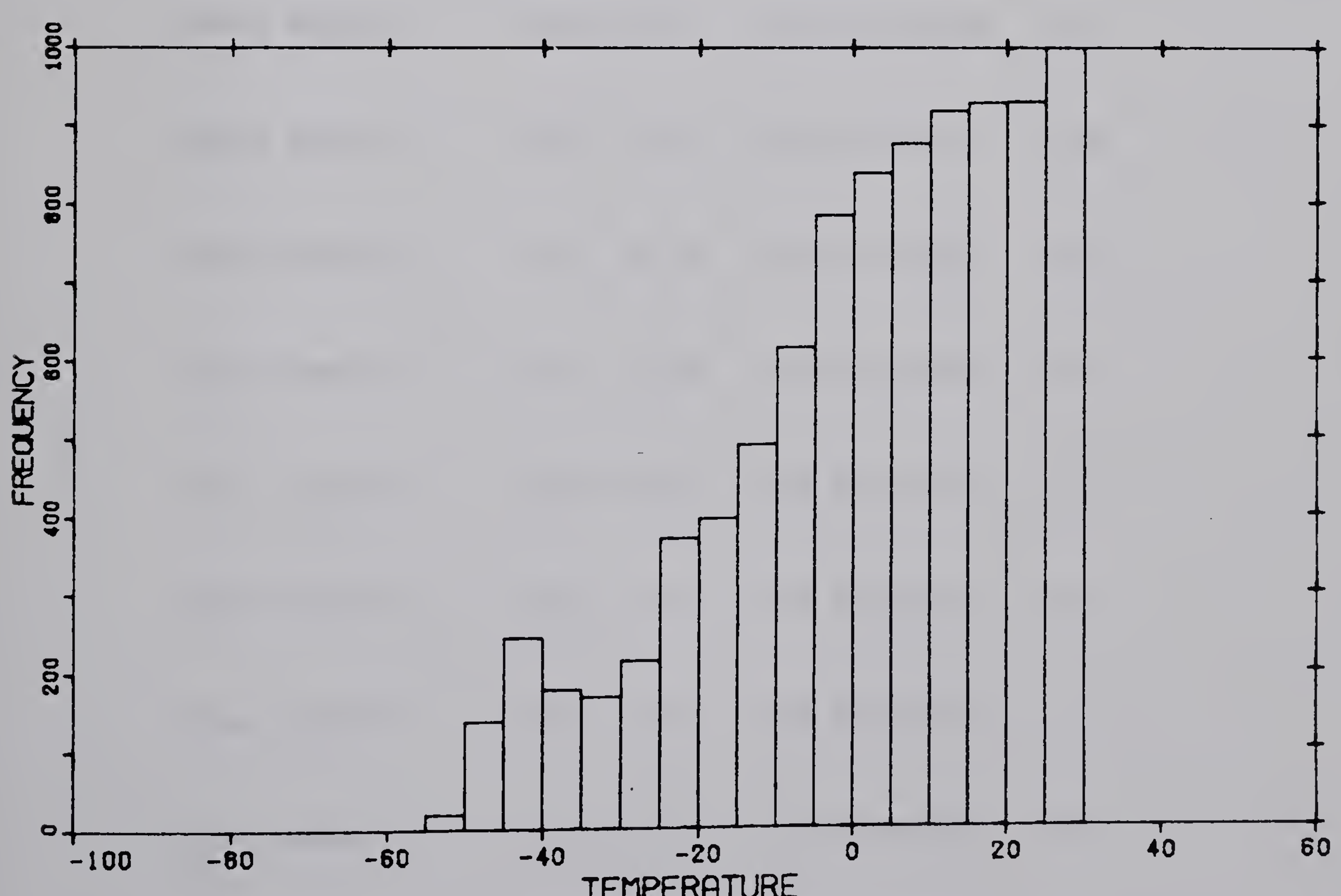


ORBIT 3970 INFRARED DATA HISTOGRAM

D.2.5 Case study #5 TIROS-N Orbit 9063



ORBIT 9063 VISIBLE DATA HISTOGRAM



ORBIT 9063 INFRARED DATA HISTOGRAM

D.3 Sample Output from Program TELEM

WEDGE NUMBER 1	MEAN 51.03	STD DEVIATION	0.28
WEDGE NUMBER 2	MEAN 81.35	STD DEVIATION	0.63
WEDGE NUMBER 3	MEAN 112.32	STD DEVIATION	0.57
WEDGE NUMBER 4	MEAN 142.84	STD DEVIATION	0.46
WEDGE NUMBER 5	MEAN 172.91	STD DEVIATION	0.41
WEDGE NUMBER 6	MEAN 203.40	STD DEVIATION	0.55
WEDGE NUMBER 7	MEAN 230.08	STD DEVIATION	0.70
WEDGE NUMBER 8	MEAN 254.54	STD DEVIATION	0.67
WEDGE NUMBER 9	MEAN 21.75	STD DEVIATION	1.08
WEDGE NUMBER 10	MEAN 98.46	STD DEVIATION	0.82
WEDGE NUMBER 11	MEAN 98.26	STD DEVIATION	0.69
WEDGE NUMBER 12	MEAN 100.89	STD DEVIATION	0.44
WEDGE NUMBER 13	MEAN 99.81	STD DEVIATION	0.91
WEDGE NUMBER 14	MEAN 137.74	STD DEVIATION	0.75
WEDGE NUMBER 15	MEAN 122.14	STD DEVIATION	0.55
WEDGE NUMBER 16	MEAN 143.21	STD DEVIATION	0.46